THE ANNUAL

OF THE

Royal School of Naval Architecture

AND

Marine Engineering.

A COLLECTION OF PAPERS ON PROFESSIONAL SUBJECTS CONTRIBUTED BY MEMBERS OF THE PRESENT AND FORMER SCHOOLS OF NAVAL ARCHITECTURE.

LONDON:
HENRY SOTHERAN & CO., 42, CHARING CROSS, W.C.
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The present number of the Annual has been published under the direction of the following Committee:—

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ROYAL SCHOOL OF NAVAL ARCHITECTURE

AND

MARINE ENGINEERING.

INTRODUCTION.

So many public schools have Magazines of their own, that, in publishing the present Annual, there is little reason to fear a charge of presumption, seeing that the Royal School of Naval Architecture and Marine Engineering has been in existence for some years, and constitutes one of the most important of the few establishments for providing technical education which this country possesses. The staff of Instructors attached to the School numbers many persons who are eminent in their respective departments, and whose contributions are certain to deserve and secure attention. Students trained in the School now occupy more or less responsible positions in various parts of the world, and have facts and opinions brought under their notice calculated to interest persons connected with the two honourable professions to which they belong. To place upon record such facts and opinions is the object of this Annual; and it is identified more closely with the School by the fact that contributions to the present number have been received only from instructors or from former or present students. Owing to the absence from England of many of the late engineering

students of the School, and the comparatively short interval which has been occupied in the preparation of this, the first number of the Annual, these students are not represented amongst the contributors, as would otherwise have been the case.

Had extraneous aid been accepted, the publication might have possessed better claims to rank as a literary production. It has been preferred, however, to trust entirely to the efforts of those who are, after all, most deeply interested in its success. In making this statement there is no wish on the part of the contributors to shelter themselves from criticism, and they venture to hope that the national importance of most of the subjects discussed, will, to some extent at least, counterbalance any faults of style or treatment that may exist. Their desire has been to explain, as far as possible in popular language, the professional view of the topics discussed, and to make the larger part of the publication generally readable, while at the same time they are not without hope that by devoting some space, as they have done, to the scientific treatment of the more technical subjects, they will be able to contribute in some small measure to the advancement of professional knowledge.

If the success of the present number should warrant it, it is proposed to continue the publication of the Annual, and it is hoped that arrangements may be made to produce it in future some time before Christmas. In styling the Annual "a collection of papers on professional subjects, contributed by members of the present and former Schools of Naval Architecture," regard has been had to the future rather than to the present. It is hoped that the members of former Schools, many of whom now occupy eminent positions, will sympathise with this attempt to popularise the treatment of subjects too often enveloped in technicalities, and will practically aid it by contributions which cannot fail to add greatly to the value of the Annual, as well as to its probable success.

THE RECONSTRUCTION OF THE NAVY IN THE 17TH CENTURY.

THE present century will always be distinguished in the history of civilisation for the successful application it has witnessed of philosophical knowledge and the exact sciences to the useful mechanical arts, and for the many important benefits that have resulted to mankind therefrom. We see at the present day a rapid development of new resources going on in every direction around us, and the forces of nature being brought more under our control, and made more available for our numerous requirements, according as the increasing spread and advance of scientific knowledge renders their character and mode of action more capable of being understood. In no one of the mechanical arts, however, has greater or more rapid progress been made than in that of naval construction, and none of them owe more to the growth of enlightened ideas and the application of abstract science. During the last forty years a succession of improvements unparalleled in magnitude and importance have been made in the construction of our ships of war, and although the necessity for a movement of that kind had long been felt, and great efforts made to bring it about, yet no progress of any value was effected till the Government of the country decided upon going to the root of the matter, and provided the means for naval architects to obtain as exact a knowledge as the imperfect state of the science would admit of the laws and principles which alone could lead to improvement and ultimate success in the profession.

Results have proved the great wisdom of the policy thus adopted, not only by the direct benefits that have accrued through the amount of technical education that has been

imparted to students of naval architecture, but also by the general spread of inquiry and the growth of correct ideas to which it has given rise, and the effect it has had in stimulating uneducated shipbuilders to the acquirement of a more extended knowledge than they would otherwise have possessed. The best naval architects of the present day are able to bring to bear upon the continued improvement of their ships all the vast resources contained in the discoveries that have been made in every branch of science that has any relation or connection with the profession, while at the commencement of the present century we find from an official statement by Professor Inman, printed by order of the House of Commons in 1833, "there was scarcely a single individual in this country who knew correctly even the first element of the displacement of one of our numerous ships, either light or load." Side by side with this increase of knowledge and ability on the part of naval architects, the progressive improvement of our ships of war has advanced with rapid strides, and in the course of a few years our navy has passed in quick succession through the following phases:—First, its sailing qualities became greatly improved; then, the application of steam power to the propulsion of ships of war, and the construction of a steam navy, followed; and lastly, the great change was brought about which has resulted in the production of our present formidable Ironclad Fleet.

A characteristic of this progressive movement, which is of great importance to us, is that England has been at the head of it, and that it is only the second time in her history that she has thus occupied the position which above all others it should be her aim to fill, seeing that she has a far greater interest at stake than any other nation in the efficiency and relative superiority of her navy. It was the same cause in both cases that placed her in this commanding position—the adoption of scientific knowledge as a basis for the construction of ships, instead of trusting to ancient maxims and empirical rules; and the use of accurate calculation, wherever this was possible, for the purpose of ascertaining from a design what properties it might be expected would belong to a ship

built from it. The result was, however, brought about in different ways, for, as we have already seen, the present advance has been chiefly due to the course pursued by the Government in the encouragement of the art, while the previous one was almost entirely the work of three or four men of exceptional scientific attainments, who devoted themselves to the work of the reconstruction of the navy.

The period in our history to which we especially wish to draw attention commenced with the reign of James I., and includes the time during which the construction of the navy was chiefly carried on by Mr. Phineas Pett, his son, Mr. Peter Pett, and Sir Anthony Deane. These men were possessed of education and acquirements far in excess of any who preceded or followed them in their respective positions down almost to our own times. Phineas Pett graduated at Cambridge; his son was a man of liberal education and cultivated taste; and Sir Anthony Deane was the most successful man of his day in adapting the scientific knowledge then in existence to the calculation of the elements of a ship.

Before referring to the improvements effected during this period we must state briefly what were the leading defects of the ships that then formed the navy of this country.

These were excessive tophamper in the shape of the towering poops and forecastles then in vogue, a consequent too great draught of water, a deficiency in the height of the lower deck ports out of water, an incapacity in fighting ships to carry provisions for their crews, which had to accompany them in small vessels called victuallers, excessive leewardliness, and an inability to sail, except in a very slight degree, to windward. These vessels were copied principally from the models of Italians, who were attracted to this country by Henry VIII. for the purpose of improving the art of shipbuilding, and very few improvements were subsequently made down to the time of which we speak, either in matters of construction or equipment. The whole of them are doubtless enumerated by Sir W. Raleigh in describing his experience, and he says that in his time topmasts had been introduced, also topsails, top-gallant-sails, sprit-sails, and studding-sails; the chain pump

had also been adopted, together with the method of raising anchors by the capstan. The large fighting ships were all two-deckers, and the largest one carried 68 guns, and was of 1,100 tons burden. These large ships were, however, very cumbrous and unmanageable, and the defects common to ships of all classes were greatly increased and multiplied with their size. Sir W. Raleigh says in his discourse on the Royal Navy and Sea Service—

"We find by experience that the greatest ships are lesse serviceable, goe very deep to water, and of marvellous charge and fearefull cumber, our channells decaying every year. Besides they are lesse nimble, lesse maineable, and very seldome employed."

The same writer also gives us an insight into the failings of the ship designers of his time, for in speaking of the importance of proper draught of water and its effect upon sailing qualities, he says—

"And that the shipwrights be not deceived herein (as for the most part they have ever been) they must be sure that the ship sinck no deeper into the water than they promise, for otherwise the bow and quarter will utterly spoile her sayling."

It is time, however, we returned to Phineas Pett. He was a Master of Arts of Emanuel College, Cambridge, and after leaving the University served his apprenticeship as a shipwright in Deptford Yard. He was appointed master-shipwright of Woolwich Yard in 1605, and ultimately became a principal officer and commissioner of the navy. He also held the rank of captain in the navy, which was conferred upon him on his taking to London a small vessel, about 28 feet long, that he had been ordered to build "for the young Prince Henry to disport himself in above London Bridge." He went to sea two or three times after this in the prince's own ship *Prince Royal*. The largest ship built by Phineas Pett while he was master shipwright was the *Prince Royal*, a two-decker, and as she was the masterpiece of her designer, and for a long time after formed the type by which other ships of her class were constructed, it will be well to notice the improvements she contained. The following account of her is taken from *Stow's Annals* :—

"This year (1610) the king built a most goodly ship for war, the keel whereof was 114 feet long and the cross beam was 44 feet in length. She will carry 64 pieces of great ordnance, and is of the burden of 1,400 tons."

From a drawing of this vessel in *Charnock's History of Marine Architecture* we find that her general appearance is very different from anything previously built, and is not very dissimilar from vessels that may now be seen lying in some of our harbours. The lofty forecastle and poop then universal is pruned down to a moderate height; the prow is taken away, and in its place is substituted a head and knee, which has, to us, quite a familiar shape. The ports are raised to a fair height out of water, and altogether she contains the leading features of our most modern sailing ships.

That the designer thoroughly understood the reasons of the bad qualities of the large ships then in existence and the remedy for them, is shown not only by the reduction of top-hamper, but by the increase of size he introduced. The *Royal Prince*, for instance, carried 64 guns, and was of 1,400 tons burden, while the *Triumph*, the largest vessel before her time, carried 68 guns, and was only 1,100, or, according to some authorities, 1,000 tons burden. This increase of size enabled him to give the ship a capacity that would render her self-sufficient in every respect, instead of being dependent on small tenders for some of her chief requirements, and it also gave a sufficient buoyancy to enable him to greatly improve the sailing qualities. After this time we hear no complaints about the bad sailing and unmanageability of our large ships, but, on the contrary, for many years after we find they greatly excelled the ships of both the Spaniards and the Dutch, the two other great maritime powers of the age, especially in sailing to windward. The real quality of the ships designed by Phineas Pett cannot be better shown than by the fact that the proportion of tonnage to the number of guns he gave to the *Royal Prince* was adopted with scarcely any modification in all future ships down to so late a period as the commencement of this century.

The success of this style of ship was so complete, that

when a commission of inquiry reported on the state of the navy in 1618, they recommended with respect to all future ships, that "they must be somewhat snugg built, without double gallarys, and too lofty upper workes, which overcharge many ships, and make them coome faire, but not worke well at sea."

The next great advance was made in the building of the *Sovereign of the Seas*. She was the first three-decked ship built in England, and almost the first in the world, but there is reason to believe that two existed previous to her, one having belonged to the Spaniards, and the other to the Swedes. She was built by Mr. Peter Pett, under the direction of his father, Phineas, who was then a commissioner of the navy. Heywood says, speaking of her builder, that "before he was full five-and-twenty yeares of age, he made the model, and since has perfected the worke which hath won, not only the approbation, but the admiration of all men." The following information respecting the ship is taken from a piece by the same writer, Heywood, which was inscribed to Charles I., and entitled, "A true description of His Majesty's Royal Ship, built this year, 1637, at Woolwich, in Kent, to the great glory of the English nation, and not to be paralleled in the whole Christian world." Her length of keel was 128 feet, length over all 232 feet,* extreme breadth 48 feet, and the height "from the bottom of her keele to the top of her lanthorne" was 76 feet. She carried 100 guns, and measured 1,637 tons burden. After mentioning a few wonderful facts in connection with the ship, he says—

> "There is one other thing above all these for the world to take especiall notice of, that shee is besides tunnage just so many tons in burthen as their have beene years since our blessed Saviour's incarnation, namely, 1637, and not one under or over. A most happy omen, which though it was not the first projected or intended, is now by true computation found so to happen."

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* The very considerable difference between the length of keel and length over all of this vessel is in a great measure occasioned by the immense projecting prow with which she was fitted, after the style of ships of an earlier period.

The happiness thus prognosticated did not fall to the lot of his majesty, for the splendour of her decorations, and the expense that was incurred in building and ornamenting her, so increased the popular clamour against the levying of ship money, by which means she was built, that the king owed his after misfortunes more perhaps to her than to any other single cause. The coincidence, moreover, was not a real one, for the methods then in use for calculating tonnage were so inexact that this ship's tonnage is stated in three different returns as 1637, 1141, and 1556.

Like many other first attempts to achieve great results, this ship was not a success as originally built, but after being cut down to a two-decker, she became one of the best men-of-war afloat. The improvement made in shipbuilding during a few years is shown by the fact, that although she was of such an unparalleled size, and was built chiefly for show, she proved to be the most serviceable ship we possessed. She took an active part in most of the great naval battles against France and Holland, and was reckoned so formidable by her enemies, that according to a writer of the period,*

"None of the most daring among them would willingly lie by her side. In the last fight between the English and French, encountering the *Wonder of the World*, she so warmly plied the French admiral that she forced him out of his three-decked wooden castle, and chacing the *Royal Sun* before her, forced her to fly for shelter among the rocks, where she became a prey to lesser vessels that reduced her to ashes. At length, leaky and defective herself with age, she was laid up at Chatham in order to be rebuilt; but being set on fire by negligence, she was, upon the twenty-seventh of January, 1696, devoured by that element which so long, and so often before, she had imperiously made use of as the instrument of destruction to others."

It has been stated in explanation of the longevity of this ship, that, according to the practice then and for many years after adopted in the North of England, the timber of which she was built was barked standing and left in that state for a time to season. In Dr. Notts' discourse, in 1687,† he mentions

* Quoted by Charnock in his *History of Marine Architecture*.

† Quoted in *Derrick's Memoirs of the Navy*.

his having been told that "all the ancient timber then remaining in her was still so hard that it was no easy matter to drive a nail into it."

We must now refer very briefly to another most important and successful innovation of Mr. Peter Pett's—viz., the introduction of frigates into the navy. The first built was the *Constant Warwick*, and Sir Anthony Deane states in a conversation, reported by Evelyn in his diary, that she was

"A trial of making a vessel that would sail swiftly; she was built with low decks, the guns lying near the water, and was so light and swift of sailing that in a short time she had, ere the Dutch war was ended, taken as much money from privateers as would have laden her; and more such being built, did in a year or two scour the Channel from those of Dunkirk and others which had exceedingly infested it."

The valuable services rendered to the country by this new class of vessels were very soon appreciated, and they gained for the designer the fame of being "the most skilful shipbuilder in the world." * After his death a monument was erected to his memory in Deptford Church, with the following inscription upon it: "Qui fuit patriæ decus, patriæ suæ magnum munimentum; he not only restored our naval affairs, but he invented that excellent and new ornament of the navy which we call frigate, formidable to our enemies, to us most useful and safe; he was the Noah of his age, by this invention, like the ark, having almost snatched our dominion of the seas and our rights from shipwreck." It is not strictly true, however, that Pett invented the frigate, for in a conversation with Mr. S. Pepys, he once stated that he took the idea from a French vessel he saw lying in the Thames.

Sir Anthony Deane developed still further in many ways the qualities of our ships of war, a striking instance of which is mentioned in *Pepys' Diary*. He says that another great step and improvement to our navy, put in practice by Sir Anthony Deane, was effected in the *Warspight* and *Defiance*, which he constructed to carry six months' provisions and their guns 4½ feet from the water. He is the first naval architect

* *Evelyn's Diary.*

we read of who attempted to design ships upon an accurate basis, or who made actual calculations for the purpose of determining beforehand the properties they would afterwards possess, for Pepys says—

"Mr. Deane and I did discourse about his ship *Rupert*,* which succeeds so well as he hath got great honour by it, the king, duke, and everybody saying it is the best ship that ever was built. And then he fell to explain to me his manner of casting the draught of water which a ship will draw beforehand, which is a secret the king and all admire in him; and he is the first that hath come to any certainty beforehand of foretelling the draught of water of a ship before she be launched."

He also wrote a book on ship construction, which, Evelyn says,

"Contains the whole mechanic part and art of building royal ships and men-of-war, being of so accurate a piece from the very keel to the lead block, rigging, guns, victualling, manning, and even to every individual pin and nail, in a method so astonishing and curious, with a draught both geometrical and perspective, and several sections, that I do not think the world can show the like. I esteem this book as an extraordinary jewel."

The progressive steps in ship construction of which we have thus hastily sketched the leading features include nearly the whole of the improvements that were made down almost to our own time. The able men who initiated and carried them out passed away, and no one came forward to fill their places. The Navy Board took the regulation of these matters into their own hands, and for more than a century after ships were built by their order according to established dimensions and tonnage, and were really only reproductions of the models and forms of the period we have been describing.

The consequence was no further advance was made, and we were at last left in the position of having to struggle against the best ships that could be constructed by the ability and experience then in existence, with vessels that, measured by the progress of other nations, had long been obsolete. In the wars between us and the Dutch during the 17th century, which was our time of greatest advance, our success was in

* Of the *Warspight* and *Defiance* class.

great measure attributed to the superiority of our ships, and considering the great ability and bravery of the Dutch admirals, especially Van Tromp, and the signal defeats he met with, it is very probable that such may have been the case. This advantage, however, was not possessed by us in any other naval war, for all through the last century the complaints of naval captains are constantly to the effect that the enemy's ships could outsail or outmanœuvre them in every possible way, and could force or avoid an engagement as it suited their purpose. The great success we had during the many engagements that then took place was won by the ability and bravery of our seamen, and that in spite of the great inferiority of our ships.

The lesson to be learnt from past experience is, we think, that the cultivation of this indispensable art should be encouraged as much as possible in this country, and that no pains should be spared to enable us to maintain a fleet superior in power and general capabilities to our maritime rivals. The cause of the standstill that followed our first period of advance was due to the fact that naval constructors then kept their knowledge of the art as a great secret, and strove to confine it entirely to themselves; thus rendering it necessary for each succeeding generation to go over the whole ground for itself with little assistance from the previous one. The different course which is now adopted, however, by ship constructors, and the endeavours that are being made to publish all that is known of theory and experience on the subject, together with the technical education that is given to those who are entering upon the profession of naval architecture, will, we hope, prevent our ever again relapsing from our present state of superiority into one of relative retrogression.

X.

OUR ARMOURED FLEET.

TWELVE years ago, the question of vital importance in connection with our navy was, shall iron-clad ships be built? France had started the new system of construction, and in many quarters there were grave apprehensions that our naval supremacy, maintained so long and so gloriously, was about to be overthrown. Other authorities continued to prefer our "wooden walls," and expressed the gravest doubts of the successful application of heavy armour to sea-going ships. On the one side, the Admiralty was blamed for delaying the construction of iron-clads; on the other they were counselled never to commence. As usual on such occasions, those who were loudest on both sides were those who had the least real knowledge of the question, and who consequently overlooked the difficulties that really existed, or conjured up phantom terrors. To revive the discussions of this period would be worse than useless: the experience since obtained has conclusively settled the main points then in dispute, and as the result of twelve years' labour we find ourselves in possession of about fifty iron-clads, of which the combined force, both for attack and defence, certainly exceeds that of any foreign navy.

It is not our intention to attempt, in this article, any detailed description of the construction or performances of existing iron-clad ships, or to estimate the respective merits of the different types. It is proposed simply to glance at the characteristic features of the various classes, and thus to trace briefly the progress of iron-clad construction; not with the idea of throwing new light upon the subject, but rather with the desire to state concisely, and in popular language, facts already recognised by those conversant with the question.

If all our iron-clads were assembled in one great squadron

and passed in review, it would become obvious to the most casual observer that by far the greater number were intended to act as cruisers, and to be capable of keeping the sea for long periods. For this purpose they have been supplied with sail-power as well as steam-power, and can proceed, if they cannot manœuvre, under sail alone. Armoured ships of the earlier types in our navy are at present doing duty on the most distant stations; and every year our Channel and Mediterranean squadrons are exercised in trials of sailing which prove ships of recent design to be at least as efficient as the earlier vessels. To enlarge upon the necessity of sail-power in cruisers is quite superfluous; and it is equally superfluous to argue respecting the advantages which result from the protection to commerce afforded by such vessels. It will indeed be an evil day for England when her ships of war cannot defend the honour of her flag in every sea, and keep open the "ocean highways" for the passage of our merchantmen. Unarmoured vessels may, and doubtless will, do much in this direction; and to a very great extent we now rely upon them; but no unarmoured vessel can hope, in fair fight, to cope with an iron-clad ship, and the special province of such cruisers in case of war would be to protect our merchant fleet from *Alabamas* unarmoured like themselves, or to act the part of *Alabamas* in preying on an enemy's commerce.

In this particular, the policy of the French has been identical with our own; and although the Americans have hitherto neglected the construction of sailing iron-clads, and depended solely upon unarmoured ships for cruising purposes, they have now recognised the folly of this course, and in the report issued by the Secretary of the Navy in December, 1869, the necessity for building ships on our models was forcibly urged. An admission of this kind, coming from such a quarter, needs no comment; and we trust that the sea-going capabilities of, at least, the greater number of our iron-clads will never be lessened by the disuse of masts and sails, in order to increase their mere fighting efficiency. Improvements in marine engineering may, of course, put a different face upon the question, but until very great improvements are made we

cannot hope to succeed in performing cruising services with steam-ships having no sail-power.

The equipment of an iron-clad for sailing undoubtedly entails greater risk of her becoming disabled in action, even when all possible precautions are taken beforehand, by sending down the upper masts and yards. The action at Lissa proves this to be the case, and even in default of that evidence there would be every reason to anticipate such a result. Hence it is far from desirable to give to a cruising iron-clad a sailing equipment as full as would be given to a ship intended to manœuvre under sail alone in action, which is the ideal of some ardent seamen. All actions will in future be fought under steam, and as far as possible with "bare poles;" but as battles are not fought every day, while cruising services have to be continually performed, we must regard the risk consequent upon the use of masts and sails as the price for sea-going efficiency and economy, and must be willing to pay it.

There are, however, exceptions to this rule, as to most others, and of late attention has been principally directed to the construction of ships having no masts or sails, intended for special services. Our two earliest turret-ships, the *Royal Sovereign* and *Prince Albert*, may be regarded as the forerunners of these special ships, but they cannot be compared in fighting-power with more recent vessels, such as the *Glatton*, *Thunderer*, and *Rupert*, which represent the most novel and powerful types of modern war-ships, and depend upon steam entirely, or almost entirely, for propulsion. Such vessels are undoubtedly of great value; they are not subjected to the risks in action attendant upon masts and sails; they possess the valuable feature of being always ready for action; and in all their arrangements the chief aim has been to increase fighting efficiency. They are, in fact, floating steam war-engines, and are not in any sense *cruising* ships, although they could fight in heavy weather if occasion were found. All are agreed on the advantage of possessing such vessels for coast and harbour defence, but there exists great difference of opinion respecting the propriety of sending to sea vessels

having steam-power only, even when the coal-supply is exceptionally large, and the chance of becoming disabled is reduced to the greatest extent by adopting independent engines and twin-screw propellers. Great opposition was raised, it will be remembered, to the construction of the *Thunderer* class, on the ground that no man-of-war should be sent to sea with only steam to depend upon; but after full consideration the Admiralty persevered in their intention to build such vessels, and we shall probably learn before long how they fulfil the anticipations of their designers. Before such trials take place, however, it seems a point beyond dispute that for special service at sea the class is very valuable, the height of the guns above water being so great as to ensure the power of fighting in very heavy weather, and the means of offence and defence being so formidable as to make it certain that they need not shun encounter with any existing ships. On occasion, the class can also be made available for coast or channel service, for the defence of our naval stations abroad, or for the blockade of an enemy's ports; and in any case will be found most useful.

The progress made in guns and armour since the *Warrior's* design may be estimated from the fact that in the *Thunderer* class the armour is 12 inches thick, while in the *Warrior* it is 4½ inches only; and that the *Thunderer* will carry but four guns, each of which weighs 35 tons, and throws projectiles weighing 600 pounds, while the *Warrior*, as originally armed, carried about forty guns, of the largest calibre then procurable, each of which weighed less than 5 tons, and threw projectiles weighing 68 pounds only. The comparison is not a new one, but it is none the less striking, and it conveys a better impression of the advance made since armour was first used than could otherwise be obtained. In view of such facts we may well ask, What will be the state of iron-clad construction ten years hence, supposing we do not change our system entirely before that time has elapsed? That this may be the case is regarded by many persons as probable; and even if this be not so, radical changes in construction will undoubtedly have been rendered necessary, for under-water attacks by torpedoes will

certainly have become more developed, and will be very generally employed whenever a naval war takes place.

One other class of our iron-clad ships demands brief notice—viz., that including vessels especially designed for ramming. This means of attack bids fair to largely replace artillery in future actions, and it has been provided for, to some extent, in all our armoured ships. In most of these vessels, however, the ramming power has been subordinated to the artillery, and it is only within the last two years that we have become possessed of specially-designed iron-clad rams. To the French belongs the honour of initiating this class; but our designers have departed very considerably from the French models, and have introduced many valuable improvements. At present there are but two of these rams in our navy; but the great value of such ships, and their moderate size and cost, renders it very probable that their number will be increased. Vessels like the *Rupert*, for example, are capable of serving either as adjuncts to squadrons or as coast defence ships, and in either case would render good service in time of need.

By grouping our iron-clads as we have done in the two divisions of sailing cruisers and ships for special services, differences of great importance have been passed over on which some notice must be bestowed. For example, in the class of sailing cruisers are included broadside ships and turret ships, the so-called "long" and "short" ships, partially protected and completely protected iron-clads, and vessels with structural arrangements of the most different kinds. To attempt any discussion of these differences would be both useless and absurd, but it may be observed that the *variety* which exists in our armoured fleet, and which has been so strongly condemned by many writers, is a necessary consequence of a reconstruction involving such radical changes, and of a progress in warlike appliances altogether unexampled. Until experience had been obtained with actual armoured ships it was doubted whether such heavily-burdened vessels could be made good sea-boats. Having begun, therefore, with partial protection in the *Warrior* as a precautionary measure, and afterwards having decided

to adopt complete protection in the *Minotaur*, one source of variety was discovered. Other motives have since led to further alterations in the arrangement of the protecting armour in later ships, and these changes, although undoubted improvements, have added to the varieties previously existing. Taking the much-discussed question of long and short iron-clads, we find another illustration of the fact that enlarged experience and mechanical improvements have been at the root of the changes made. The introduction of a new type of marine engine, and the saving in the weight of the hull resulting from improved structural arrangements, has rendered it possible on smaller dimensions to accomplish greater results. From the facts respecting steam-ship performance in their possession, the advocates of the short ships predicted, it is true, that extreme length was not essential to high speed, and the result has proved them to be in the right; but until trials had been made the question remained an open one. Now, we know that the shorter type is to be preferred, and we act upon the knowledge. In this case, as in many others, theoretical demonstrations have followed, not preceded, practical proofs.

The whole tendency of this great reconstruction has, in fact, been towards the sacrifice of uniformity to efficiency, and any changes which have been shown to be desirable have been made. By this means we have passed step by step to more and more striking results, and have been enabled to increase the offensive and defensive power of our ships to an extent which was undreamt of ten years ago. With our enlarged experience we now see reason to regret many of the steps which have been taken, but the wonder is that, under the peculiar circumstances of the period, we have not greater variety in, and more reason for complaint respecting, our armoured fleet. No such extravagances in form and construction exist among our iron-clads as can be found in most foreign navies. We have no *Dunderbergs*, or *Pervenetzes*, or *Boule-Dogues*, or *Affondatores*, to show what strange ideas of construction may influence practice in a time of transition. Not that our designers were unsupplied with ample materials for the purpose had they been inclined to depart from what

had previously been considered "ship-shape," as any one may see who turns over the pages of the Reports of the Iron Plate Committee. In spite of these temptations our earlier iron-clads were made *sightly*, as well as powerful, ships; and the wisdom of this course has since become generally acknowledged.

The question of turret *versus* broadside ships has attracted so much attention that little need be said respecting it here. Any one who looks over the papers and discussions of ten years ago will, at first, be astonished at the progress which public opinion respecting the capabilities of the new system has since made. Then, it was thought doubtful whether guns should be mounted in turrets in any but coast-defence ships, and the plans for carrying the system into effect were in a most crude condition. Now, the arrangement is acknowledged to be successful in sea-going as well as coast-defence ships, and is admitted to be capable of expansion to a very much greater extent. But this progress has taken time to effect, and the advance has been a gradual one. All through the period intervening between the introduction of the plan and the present time, its advocates have been claiming for it more credit than it deserved, and its opponents have been scarcely doing justice to its merits. Opposition and delay have, however, had some good effects, and it is now evident that we have, in the long run, benefited by the principle, so strongly insisted upon by the Admiralty, that sufficient trial should be given to each new type of turret-ship before other vessels of the class were built. Had it been otherwise our fleet might have contained more than one *Captain*, and the disaster of last September might not have stood alone. But even with this slow progress in turret-ship constructiou, differences quite as striking as those existing amongst broadside ships have crept in, and the reason is obvious—uniformity has here, as elsewhere, been very properly sacrificed to efficiency.

It has been asserted that the variety existing amongst our iron-clads might be an advantage in an action instead of a disadvantage; and, to some extent, this is probably true, as general actions will, most likely, be fought at comparatively

low speeds, when vessels, having very different full speeds, could act together. Whether this be so or not, it seems clear that we have gained by the variety consequent upon possessing turret as well as broadside ships, as well as from the improvements consequent upon the keen rivalry of the advocates of the two systems. As compared with France and America, our only maritime rivals of importance, we occupy a most advantageous position. France has but one true turret-ship, America has no broadside iron-clad, and we have a strong force of both classes. Our rigged turret-ships are, it is true, but few in number, and the loss of the *Captain* may have the effect of retarding our progress in this direction; but the *Monarch* affords a proof of the possibility of combining safety with efficiency in a cruising ship with turret armament, and only those unacquainted with the subject will confuse the question of safety with that of the method of carrying the guns. The construction, or non-construction, of rigged turret-ships will, we think, be decided not upon such grounds as these, but on the possibility of effecting the combination of a full rig, and properly supported masts and spars, with an all-round fire from the turret guns. That this is the critical point in dispute is now generally recognised by authorities on both sides.

It is most interesting to remark how, in the competition between the rival systems of armament, the faults pointed out by the opponents of each have been remedied in later designs. This is especially true of broadside ships, which have gradually been made to approach to the ideal of perfection put forward by the advocates of turret-ships—viz., the possibility of commanding all points on the horizon with protected guns, without making the vessel change her place. With a fixed battery it is obviously impossible to obtain all the advantages in this respect obtainable with a revolving turret which carries the guns; but, on the other hand, in recent broadside ships a nearly *simultaneous* all-round fire from protected guns carried amidships has been secured, and there are some who think this power preferable to the uninterrupted command of the horizon which the turret-ship may

be made to possess. Between two such great advantages we do not profess to be able to choose, seeing that competent judges differ so widely in their conclusions. Under some circumstances the *simultaneous* all-round fire would be preferable, under others the concentrated fire which the turret guns may deliver on *any* point would be most advantageous. Is it quite impossible to combine the two features in one ship, or is it desirable to make the attempt?

The principle of *concentration* now so generally recognised and acted upon in iron-clad construction, received its first development in turret-ships, and the fact is the more worthy of record, because when our first turret-ships were designed, we were building completely protected ships, in which the guns were distributed along the whole broadside. Ever since that time we have been increasing the weight and power, but diminishing the number, of the guns carried by war-ships. In broadside ships we have passed from vessels like the *Minotaur*, having the whole broadside protected, to vessels like the *Bellerophon* or *Hercules*, having armoured batteries at the central part and at the extremities, associated with protection along the whole water-line; and thence to the ships of the *Audacious* class, with double-storied batteries amidships. In turret ships we have changed from four turrets, as in the *Royal Sovereign*, to two turrets in most vessels, and in some cases to one turret only, as in the *Glatton*. This latter plan certainly affords the limiting example of concentration, and objection has been made to it because of the risk consequent upon putting all the guns into one turret, or, as some prefer to phrase it, "putting all the eggs into one basket." In this objection there is great force; but even in face of it, there is reason for admiring the simplicity and efficiency of an arrangement which enables the whole horizon to be swept by two very heavy guns carried in one revolving tower.

Did space permit much more might be said respecting some features of our iron-clads, no less characteristic than those to which attention has been directed. Chief among these stand their structural arrangements, to which so much of the superiority of our ships to foreign iron-clads is owing.

The subject has been fully discussed, however, elsewhere, and it is only necessary to say that there are now few dissentients from the opinion that, by building in iron, we have gained greatly in strength, lightness, and safety, besides putting it out of an enemy's power to deprive us of our supply of materials in time of war, and advancing our iron manufacture and merchant shipbuilding to a surprising extent.

Our armoured fleet has not yet had to bear the brunt of actual fighting, and we have but little to guide us in forming a judgment of its powers beyond the single action at Lissa, and the engagements which took place during the Civil War in America. But when compared with foreign ships, either as respects construction, armour, armament, speed, or other important qualities, our ships take so high a place, that we have little to fear from a conflict. This conclusion is the more satisfactory, seeing that such vast sums have been spent upon our iron-clads and upon experiments connected with their construction. The British tax-payer may rest satisfied that in this case his money has been well-spent, and in view of the heavy requisitions which would follow a successful invasion, he may be expected not to complain of a slight increase in his burdens, should occasion arise to strengthen that navy which constitutes our "first line of defence."

H.

POPULAR FALLACIES IN REGARD TO SHIPS.

The subject of popular fallacies is a deep and a wide one, for they exist in reference to almost every conceivable matter. It is proposed in the present article, however, to consider merely popular fallacies regarding ships; this branch being of itself an extensive one, for the fallacies concerning the theory of ships are certainly neither few nor unimportant. Of this we have lately had ample proof in the newspaper correspondence which has resulted from that sad catastrophe, the loss of the *Captain*, and in the different opinions upon the cause of the same, which have been advanced and discussed in the public journals.

The result of the examination at Portsmouth was not altogether satisfactory to those who were anxious to master the subject of a ship's stability. If they commenced the study in a thick fog they ended it in a thicker. We remember the old proverb, "When doctors disagree," &c., and doctors did disagree in their evidence; one doctor, well known as a master of his subject, having made his experiments and calculations upon the *Captain's* stability, being, without further proof, simply discredited by another doctor who had not made any experiments or calculations whatever, even if he were able to do so. That the evidence taken at the court-martial did not clear away, but rather thickened the fog which enveloped the popular mind in its notions of ships' stability, was evident to all; and some of our non-scientific journals, in their capacity of public teachers, thinking that this was not a right state of things, made a laudable attempt to render everything clear, but succeeded only in making confusion worse confounded, and in exemplifying the truth, that when a man essays to teach that of which he himself is ignorant his failure is certain. That this general ignorance on an important subject should exist is to be wondered at when we consider that the few principles upon which the stability of a ship depends may almost be learned in an hour by an intelligent person, from any work on hydro-

statics or the theory of ship construction. With these introductory remarks we will proceed to consider in detail some of the more current popular fallacies regarding ships; and in doing this we may as well commence at the beginning.

Nobody doubts that a *wooden* ship will float; a piece of wood floats, and therefore any number of pieces put together will float; but an iron ship—how about that? Ah, that is another matter; a piece of solid iron will not float; how, then, can a large piece of iron like a ship float? It was a popular fallacy when iron ships were first talked about, that it was impossible such ships could float, and, laughable though the idea may be, there are even at the present day some people who would doubt that an iron ship ever could, would, or should float; or, if they were obliged tacitly to admit the fact, would be quite at a loss to explain it.

A little reflection would enable these persons to perceive that, although a solid piece of iron does not float, you might cut out all the interior part, leaving just a thin skin, until your piece of iron was even lighter than your solid piece of wood of the same size, and then there would be no reason why the one should not float as well as the other.

The truth is, that anything will float in a fluid, no matter of what substances the body is composed, if its external bulk is such that it displaces a quantity of fluid whose weight is greater than its own, and that when the body is floating at rest, the weight of water it displaces will be *exactly equal* to the weight of the body. This is the first law of floating bodies.

But if there are some who cannot explain why an iron ship should float, there must be more still who are unable to tell you why it should float in the position it does, in preference to any other. Observation will have shown them that it has some connection with the position of the weights on board, as well as with the form of the ship itself; and that either end of the ship will sink more or less deep in the water according as weights are put into or taken out of that part of the vessel; but they will not be able perhaps to state exactly the principle involved—viz., that for a body to float at rest in a fluid, the centre of gravity of the displaced fluid and the centre of gravity of the body must be in the same vertical line, which is the second law of floating bodies, these two laws giving both the

necessary and sufficient conditions for the equilibrium of a floating body.

Again, on the subject of stability of ships, very strange and curious notions are popularly entertained, simple though the principles are upon which it depends. As before remarked, the sad loss of the *Captain* has brought to light a number of very heterogeneous and contradictory views and opinions that exist on the subject, the reading of which excites one's laughter and ire in turns. Among the explanations of the cause of a ship's capsizing, we have met with such as the following: that "the centre of gravity got outside the point of support!" that "the ship lost her centre of gravity!" and many others equally or more absurd.

The simple reason why a ship when inclined tends to return to the upright position, the force or forces at work to produce this tendency, and the measure of that force or those forces, seem very rarely to have been comprehended by the writers.

A London newspaper thus attempts to set its readers right on the matter. We quote the sense, not the exact words. When a ship is inclined, it says, the pressure of the water on the sides tends to restore the ship to the upright position; but the total pressure may be supposed to be acting through one point; this point is called the metacentre. If this point is above the centre of gravity of the ship, the ship is stable, and *vice versâ*.

The above sounds very much like a definition of the centre of buoyancy, which in a ship never is above the centre of gravity, and therefore no ship would be stable judged by this test. The writer, by reference to any work on hydrostatics, might have obtained a correct definition of the metacentre. Without reference to a figure it would be somewhat as follows: Suppose a body is floating in equilibrium in a fluid, the verticals through the centre of buoyancy and centre of gravity are in the same straight line; suppose the body displaced through a certain angle, then a vertical through the new position of the centre of buoyancy will intersect the former vertical in a certain point; when the angle of displacement becomes infinitely small, this point is called the metacentre. If this point is above the centre of gravity of the ship, the vessel is stable, and *vice versâ*.

Again, supposing we have a body floating in stable equili-

brium in a fluid, and it be displaced through a given angle, the weight of the body is still acting vertically downwards through its centre of gravity; the resultant pressure of the water, equal to the weight of the body, is still acting vertically upwards through the centre of buoyancy; but these two forces are no longer directly opposed to each other, but form what is termed in mechanics a *couple*—viz., two equal forces acting upon a body, in parallel but opposite directions, at a certain distance apart. This couple will tend to restore the body to its original position, with a force varying directly as the weight of the body and the distance between the directions of the forces called the arm of the couple.

In order to express the absolute value of the statical moment of force tending to restore the body to its position of equilibrium, we must adopt some convenient unit; this is usually taken as a couple, of which the forces are each one ton, and the arm of the couple one foot in length, so that the result would be so many *foot-tons*.

Apropos of this unit there was a letter published in the *Engineer*, the writer of which took to task the President of the Council of Construction for using the expression *foot-tons* in relation to a statical moment of force, and says, with a sneer at the science in vogue at the Admiralty, if there be one thing in mechanics more firmly established than another, it is that foot-tons means *work*. The knowledge of mechanics possessed by the writer of this letter must be very limited indeed, for every one knows that, although in mechanics foot-tons often means work, yet it as often means something quite different.

We may have a pound (weight) and a pound (money), so in mechanics we have a foot-ton of work—that is, a ton weight raised one foot high—or we may have a foot-ton of statical moment—that is, a force of one ton acting at a distance of one foot—and to say that the righting force acting on a ship when inclined is 6,000 simply, as the writer of the letter says it should be, is absurd, and has no meaning whatever—in fact, a statical moment of force can only be measured by adopting some such unit as a foot-ton, foot-pound, inch-ton, &c., it matters not which.

A popular fallacy regarding ships, and one which has received frequent expression of late, is that additional immersion always means additional statical stability. One writer in a provincial

paper, in a discussion on the *Captain*, expresses his opinion that if it had not been for the extra stability gained by the additional two-feet immersion over her designed draught, she would have turned bottom upwards when she left the stocks; and when pressed for his reason for so thinking, tells us that with the greater immersion the ship would have "greater hold upon the water." Surely ignorance of the matter had got a great hold of the writer, for the least knowledge of principles would enable one to see that had the *Captain* floated at two feet less draught than she did, she would, in all probability, by virtue of the great increase in her maximum angle of stability, have passed safely through the ordeal to which she succumbed.

With an ordinary ship, floating at her load draught of water, additional immersion would generally result in a *decrease* of stability; but whether it would or not in any particular case would depend of course upon whether the metacentric height was diminished or not, and this would be determined by the following considerations:—

Suppose a ship floating at a given draught, with a certain height of metacentre above centre of gravity; then if her weight is so increased that she floats at a deeper draught while her centre of gravity is not altered, the centre of buoyancy will have been raised in reference to the centre of gravity, or to the keel of the ship; therefore, if the height of metacentre above the centre of buoyancy, given by the formula—moment of inertia of *plane of flotation*, divided by displacement, is diminished to the same extent as the centre of buoyancy is raised, the metacentric height will be the same as before; if to a less extent, the metacentric height will be greater than before the increased immersion, and *vice versâ*, and this metacentric height is a comparative measure of the stability. The height of the metacentre above the centre of buoyancy would be decreased in ordinary ships, for while the moment of inertia of the plane of flotation would be nearly alike before and after the increased immersion, the displacement would be increased. It would depend, as before stated, upon the relative distances through which the centre of buoyancy was raised and the height of metacentre above centre of buoyancy diminished whether the ship in the new position would be more or less stable than before. In obtaining the absolute amount of stability in the two cases, we must remember that in the second

case we have increased the forces of the righting couple in the proportion of the new to the old displacement, and that therefore we may decrease the arm of the couple, and therefore the metacentric height, in the same proportion, and still retain the same absolute measure of stability.

From the above considerations we see that the notion that increased immersion *necessarily* means increased stability, although a common one, is notwithstanding fallacious—in fact, the deep, narrow ship is the type of vessel which possesses very small stability, while the wide, shallow ship is the type of vessel which possesses very large stability.

But the complete consideration of the statical stability of a ship involves more than the mere knowledge of the metacentric height, which, as has already been implied, is absolutely true for an indefinitely small angle of heel only, and very approximately true for moderate angles (say to ten degrees), but not to be depended upon for large angles of heel for ordinary ships; or, perhaps, for moderate angles of heel in ships of peculiar or abnormal form. In these latter cases the actual righting moments at any given angle of heel must be calculated by more exact, and, at the same time, more tedious methods.

An example of a departure from the ordinary type of ships becoming dangerous to the stability at large or even moderate angles of heel, is that of a low freeboard turret-ship, in which the centre of gravity would necessarily be high, and the deck would begin to be immersed at a comparatively small angle of heel, in which case the centre of buoyancy, instead of moving out faster than the centre of gravity, and the forces acting through these points thus forming a righting couple, approximately proportional to the angle of heel, as would be the case in a high freeboard ship, would move less fast, and would soon be overtaken by the centre of gravity, and the two be again in the same vertical line, in which case the ship would be in a position of unstable equilibrium, and if she passed this point would capsize altogether. Thus we see the constant source of danger that would exist in low freeboard turret-ships carrying a large area of sail, or, in other words, a low freeboard ocean-cruiser.

It has been pointed out in a letter to the public journals that the foundering of the *Captain* does not show that low freeboard ocean-cruisers cannot be made perfectly safe, for, says the

writer, height of freeboard must be considered in relation to breadth of beam; one ship of twice the beam of another, would, other things being equal, possess eight times the stability, and therefore, his argument is, we can get any amount of stability we choose.

Of course we can if we want to build a tub, or even, perhaps, a floating battery, but certainly not if we want a ship for ocean cruising. In designing a ship we are confined for proportion of length to breadth, at least within some limits; and if we increase the breadth to a great extent, we must increase the length and the other dimensions, and we simply get a ship of increased size to which we must give proportionate sail power to make her what we want her to be, an ocean-cruiser; and the same elements of danger exist as in the smaller ships—in fact, for the edge of the deck to become immersed (which is the beginning of the danger) at the same angle as in the smaller ship, the height of freeboard must be increased in direct proportion to the increased breadth.

There is another phase of ships' stability which must receive a passing notice, as upon this also much misapprehension exists; and that is what is termed the *dynamical stability;* by which term is expressed simply the *mechanical work required to be done to heel a ship over to a given angle.*

Thus while the *statical stability* at a given angle expresses the moment of force which, at that instant only, is being exerted to right the ship, the *dynamical stability* expresses the whole work done, in inclining the ship from the position of rest through the given angle; and the one has a direct relation to the other.

There is one other fact in connection with this subject which is too important to be overlooked, but which is sometimes left out of the question when discussing the measure and extent of a ship's stability; and that is, that if a force which, steadily applied, would *keep* a ship heeled over to a certain angle, were suddenly and continuously applied when the ship was in the position of rest, it would cause the vessel at first to heel over considerably past the said angle—in fact, approximately to twice that angle, or even more than this in cases where the righting moment did not increase proportionably to the angle of heel.

That this must take place is seen from theoretical considera-

tions, but it has likewise been demonstrated by experiments on models. From this we see that a ship must not only possess sufficient stability to meet the steady pressure of the wind on the sails, but also a reserve of stability to meet the effects of sudden increases of pressure.

But we must hasten to notice certain popular fallacies in regard to other matters connected with ships besides their stability. Projecting prows, or what may be termed the swan's-breast contour of stem, have furnished rich ground for the growth of some of these deep-rooted fallacies. One of them was the notion that this kind of bow was necessarily associated with the idea of "ramming," that the form of stem itself declared the intention, and that the two things were inseparable. And when a small unarmoured wooden corvette which had this kind of bow, but whose intentions as regard ramming were of the most honourable kind, was, much against her will, made to run into another vessel, and went to the bottom in consequence, the cry was immediately raised, "that settles the ram bow question;" whereas the point decided was, that it is dangerous to employ a vessel for a purpose for which she was never intended. The truth is, that this particular contour of the stem, in conjunction with what is known as the U-section, arose out of an attempt to combine fine water-lines with increased buoyancy at the bow.

Then, again, on the subject of the size of armour-clad ships, in relation to the thickness of armour they had to carry, we all used to have very false impressions, which were given to us, of course, by those who were the recognised authorities on the subject. With our first attempt at producing a real armour-clad sea-going ship, admirable though the result undoubtedly was, we united the firm conviction that a ship of 380 feet in length was absolutely necessary to carry a partial protective coating of 4½ inches of iron, and when we attempted to advance a step farther, and to employ armour of 5½ inches thick, a vessel 400 feet long was designed for the purpose of carrying it; and as in the great contest between guns and armour, the thickness of the armour has had to be continually increased, to enable it to resist the enormous penetrating power of modern rifled ordnance, so our ships must have gone on increasing in size until they were too large for any of our existing docks or basins

to contain them, and their prodigious first cost, and cost of maintenance, would have only been matched by their extreme unhandiness and uselessness. But the illusion has been dispelled, and the first symptom of a return to true principles was the production of a vessel 100 feet shorter than our first iron-clad, steaming at the same, or very nearly the same, speed, infinitely more handy, but also more heavily armed, and with the guns and vital parts of the ship protected with 6 inches of armour. Since then we have seen ships of very small tonnage indeed carrying armour as thick as this, and we are now employing armour of as great a thickness as 15 inches, in ships which are as yet far from having attained the gigantic proportions of our first ironclads.

Again, the subject of the proportion of length to breadth in relation to speed, and also to the weights the ship has to carry, is one of the popular notions upon which we have received some very rude shocks lately. Everybody used to think that great speed could not possibly be obtained without great length; and we forgot that we might compromise the matter by decreasing the length and increasing the engine power, and by this means, in view of the particular purpose for which she was intended, produce a much cheaper and more efficient ship. We have had to learn this, and it has taken time. It was necessary to have it practically exemplified in the *Bellerophon*, for before that ship was tried, her failure was pretty generally predicted; fourteen knots with a proportion of length to breadth of little more than 5 to 1! "Impossible," said some; "against nature," said others. But the ship was built and tried, and obtained the speed for which she was designed, with something to spare, and the thing was proved.

Wait a bit, said the objectors; we have one little test which will soon prove whether your ship is worth anything or not. What is your constant? Constant? Yes; your constant given by the formula: $\frac{(\text{speed})^3 \times (\text{displacement})^{\frac{2}{3}}}{\text{I. H. P.}} = c$, or by the formula: $\frac{(\text{speed})^3 \times (\text{area of mid. sec.})}{\text{I. H. P.}} = c_1$, for that is the true test of the ship's efficiency. Well, we are obliged to confess that the constant thus obtained is low compared with that exhibited by long, fine ships; but all this might have been foreseen, and is, indeed, a part of the design, for if this constant had been

overrated, how could the ship have obtained her calculated speed?

But, allowing the constant to be low, the conclusion therefrom of the inefficiency of the ship is altogether illogical. What does this low constant tell us? It tells us this—that, comparatively speaking, we are not driving our ship through the water quite so economically as we could drive a longer and finer ship; but it tells us nothing on the other side of the question; it is silent regarding the enormous saving in first cost of the shorter over the longer vessel; it says nothing about the reduced cost of maintenance by adopting the shorter type; it is silent regarding the extreme handiness of the shorter as compared with the longer ship—in fact, it is silent on all points but the one mentioned, and therefore the results of the above-quoted formulæ are no true test of the efficiency of a heavy-armoured and armed fighting ship, for it cannot be sacrificing the efficiency, if, by making a compromise, we gain on one side ten times more than we lose on the other.

We do not want to quarrel with the formulæ; all very good, and very useful, like most other things, in their place; but very misleading when misapplied; and we have seen that they are woefully misapplied—for instance, in seeking to test by them alone the true comparative efficiency of a heavily-armed and armoured fighting ship.

They are most applicable, of course, to testing the comparative efficiency of ordinary merchant steam-ships; but even here we can imagine cases in which the constants given by the above formulæ, since cargo-carrying power is left out of the question, would not fairly test the efficiency, when that efficiency is considered, as it would be practically, in the light of the interest returned on the cost of the ship. It would be possible to build a ship whose entire efficiency should consist in her good constant, which we can imagine would be a *constant* source of annoyance to her owners, if they anticipated getting any return for their outlay. We are far from having exhausted our subject, but with this little desultory talk we must leave the rest for future consideration.

H. E. D.

THE LOSS OF THE "CAPTAIN."

Most of us are prone to underrate peril which has been successfully braved, especially if we are not assured of its presence by the memory of some calamity which it has wrought. A soldier who has passed unhurt through several campaigns, although his comrades have fallen at his side, grows to make light of the whistle of bullets around him, and can scarcely realise the feelings which at first the now familiar "whew" stirred up within him. We go upon the Serpentine when the ice is alive with skating and gaiety without any of the misgivings which we should feel if we ventured on in the grey dawn, with not a soul near, and the state of the ice scarcely visible for any distance.

These reflections arise in our minds by contemplating the changes which have taken place in the minds of the public within the last few months regarding low deck sailing monitors. Considerable apprehension was always felt by the profession as to their safety, and this was much increased by the paper read by Mr. Reed before the Institution of Naval Architects three years ago, in which he clearly illustrated the dangers to which they were subject. The *Captain* was building at the time, but she was considered then to be a ship of 8 feet free-board. When complete, however, her freeboard proved to be only 6 feet 6 inches, and with this height of side she was sent to sea. The report of her behaviour was such as to carry public opinion by storm, and the chorus of praise bestowed on her continued to increase until the news arrived of the terrible disaster which has made so many homes desolate, cast a gloom over the whole country, and stained the pages of our naval history.

It is not possible as yet to form a full and impartial judgment on the events which have led up to this tragedy. We have learned much from the evidence given before the court-martial; but much yet remains to be told; and we hope that the subject, painful as it

is, will be revived again and again, until the baneful influences which foisted on the country as seaworthy this treacherous ship, so soon to become the coffin of many of our bravest sailors, shall have been exposed so effectually as to render them innocuous in the future. The almost instantaneous destruction of 500 British seamen, unconscious of danger, is an event which is so appalling, that to dwell upon it would be too painful. The memories of Captain Coles and Captain Burgoyne will not fade. The former has left us a noble monument in the turret system, the creation of his brain; and brave Captain Burgoyne will be remembered as one who, had he lived to see a war in which the naval force of England could meet a foe worthy of her steel, would have rivalled the glorious deeds of Nelson and of Collingwood.

From what we have already said, it will be inferred that we do not pretend to deal with all the points connected with the sad story of the *Captain*. We purpose rather to indicate as briefly as we can those to which we think attention should be specially directed.

We will not dwell upon the events which led to the decision of the Board of Admiralty, to place her design in the hands of a private firm rather than in those of the Chief Constructor of the Navy. On this point we accept the verdict of the court-martial, that it was in deference to external pressure brought to bear on them. After this, the first question which presents itself is: was the Controller's department in any way responsible for the ultimate behaviour of this ship, designed by Messrs. Laird and Captain Coles, after the slight which had been cast upon them by her design being taken out of their hands on the assumption of their prejudice against ships of her type? There seems to have been no doubt existing in the minds of Mr. Reed and Mr. Barnaby, that their department was entirely free from any responsibility. Messrs. Laird repudiate the view that they were responsible for the behaviour of the ship after the design had once been accepted by the Board of Admiralty and the contract entered into. This is a point which we hope will yet receive proper judicial consideration. It will be watched with anxiety by foreign governments desirous of having ships built by private firms in this country; for it is of grave interest to them to ascertain, if they accept a design of a ship from an English firm who

engages to build her, and that ship immediately on going to sea founders from no fault of seamanship, but from sheer unseaworthiness, whether they can demand that the money paid for her shall be refunded. A somewhat similar case would arise between an architect and a private gentleman who employed him to *design and build* a house, in the event of the house toppling down as soon as built.

It should be noticed that when the Admiralty received the designs for the ship from Messrs. Laird, they ordered the Chief Constructor of the Navy to report upon them. Mr. Reed did report upon them twice. The first report, which it appears was a preliminary one, was rather favourable than otherwise. In the second report, which soon followed, he entered more into detail. Its tenor may be gathered from his evidence before the court-martial. He says that he pointed out the insufficiency of the data in his hands to enable him to enter into elaborate calculations to prove the accuracy of the design. His experience led him to cast doubt upon the statement of weights given by Messrs. Laird unless great care were taken in the building, and also upon the stability of the ship—the two points (as he says) in which she proved defective.

These doubts of the Chief Constructor were conveyed by their Lordships to Messrs. Laird, who replied that they had satisfied themselves with regard to them. It does not appear that the latter forwarded to the Admiralty their calculations on these points, or the necessary additional data required by the Chief Constructor to enable him to calculate them. Neither does it appear that the Board of Admiralty asked Messrs. Laird to do so. Great weight, it seems to us, should be attached to this in determining the share of responsibility as between the Admiralty and the designers. It seems clear that the former relied entirely upon the latter as to these two all-important points in the design, but whether this reliance necessarily entailed responsibility on Messrs. Laird, and could therefore be justified by the Board of Admiralty, we will not attempt to decide.

The fact remains that by the contract entered into for building the ship Captain Coles and Messrs. Laird became responsible for her, and on their hands all the unspecified parts of the ship were left entirely; the only points to which they were tied were carrying out the contract according to the plans and specifications,

and subject to supervision as to quality of materials and workmanship. The ship was accordingly built at Birkenhead, and floated out of dock in the spring of 1869.

When completed, about a year afterwards, it was discovered that she would float some two feet below her intended waterline, and that about 900 tons had been put into her above the estimated weight. This laid bare the fact that, either in designing or in building the ship, an alarming blunder had been committed. None of the evidence appears to show that when the magnitude of this error was discovered by the Admiralty, they manifested any disposition to treat it as sufficiently grave to justify their leaving the ship on the hands of her designers. Neither does it appear to have occasioned any immediate distrust of the ship's stability. A striking point is that Messrs. Laird, before the ship was completed, appear to have doubted their previous calculations, and Mr. William Laird, in his evidence at the court-martial, says that in February, 1870, they performed new calculations to determine the position of the centre of gravity, and so satisfied themselves.

This proceeding of Messrs. Laird's, in finding by *calculation* the position of the centre of gravity, is inexplicable. With the ship floating for months before their eyes in a comparatively finished state, and in a place where she could easily have been heeled, this would have been a far more speedy and sure way of ascertaining it. Messrs. Laird's reason for not heeling her is, that she was not complete at the time; but whatever weights had to go on board after that time were known, and their effects could have been computed. In fact, the calculation which they put forward, and which was based upon the weights actually in the ship, was, of course, subject to the same modification for weights to go on board.

The ship remained afloat at Birkenhead for about a year, before she put to sea on her voyage round to Portsmouth. When ready to start, she was delayed several days owing to the inclemency of the weather. Up to this time the calculations for the stability of the ship had been entirely intrusted by the Admiralty to Messrs. Laird. This was a critical period in the ship's history. She had never been to sea, and consequently a great deal of uncertainty must have been felt by all interested in her.

If her designers had not adopted every means in their

power to satisfy themselves of the safety of the ship, she should not have been sent out at an inclement season of the year on her passage to Portsmouth. Much depended on that first passage as regards the confidence which would be afterwards placed in her. She met with cross-seas, and she is reported to have behaved splendidly, without showing the least symptoms which could cause uneasiness. From this time praise began to be bestowed on her seaworthiness, and her success was soon looked upon as an accomplished fact.

At the time she arrived at Portsmouth she had not been delivered from the hands of the contractors into those of the Admiralty. When there, it became the duty of the dockyard officers to survey her, with a view to the transfer taking place. The limits of this survey did not extend to the ship, as considered from the naval architect's point of view, but, as in the case of all contract-built ships, to the structural details and arrangements, from the point of view of the shipbuilder. If the confidence of the Admiralty in Messrs. Laird had been shaken by the disclosure of the errors in weight which had been committed, and which were now certainly discovered, this, it seems to us, would have been a favourable time to pause and consider the position in which they were placed. They could have directed the Chief Constructor to take steps to reassure himself by the necessary trials and calculations respecting any doubts which might still be lurking in his mind regarding the ship. It will probably never be known satisfactorily why this course was not adopted, or to what extent the confidence of the Admiralty in her designers was strengthened by the reported admirable behaviour of the ship in her somewhat rough passage from Birkenhead to Portsmouth. That this had some effect we cannot for a moment doubt. The grave complications which would have arisen if the professional officers of the Admiralty had pronounced her unfit for sea are obvious, and it is not to be supposed that their Lordships would risk these complications as long as they had such grounds for faith in the ship. She remained at Portsmouth until the early part of May, and then went to sea. Before this Messrs. Laird proposed to the Admiralty that she should be inclined to find the position of her centre of gravity. They were informed that it should be done as soon as convenient. It was not done until the latter end of July.

Let us consider for a moment what the circumstances were. Until then the whole question of the position of the centre of gravity had been left entirely in the hands of Messrs. Laird. No one but themselves could say what was the minuteness of the calculations they had made on this point. They had placed sufficient faith in those calculations to induce them to trust the ship in the Irish Channel without previously inclining her at Birkenhead. The Admiralty had placed sufficient confidence in them to acquiesce in this step. After the ship has been at Portsmouth for some time they propose to the Admiralty that she shall be inclined. How is this proposal to be interpreted? If they did not place confidence in their own calculations we cannot understand their not inclining her at Birkenhead before sending her to sea at all. If, after the ship reached Portsmouth, they discovered that these calculations were unreliable, they would no doubt have conveyed their proposal to the Admiralty in a way which would have insured prompt action being taken in the matter. If, as we think is more likely to have been the case, they had sufficient confidence in the practical accuracy of their own calculations to feel assured of the safety of the ship, but wished to possess an accurate record for future guidance if it could be obtained without their finding it for themselves, we can understand their course of action; and we can also understand the action of the Admiralty, if they too considered it in this light, in not allowing the inclination experiment to interfere with the other trials of the ship, which were being rapidly pushed on with. This was evidently the view taken by Mr. Reed, if we may judge from his evidence before the court-martial.

The *Captain* started on her first cruise on the 10th of May, and returned early in June, having been at sea about a month, in company with other ships, under the watchful eyes of some of the ablest seamen in the Navy, among the ranks of whom were enthusiastic admirers and hostile critics. She sailed again on her second cruise on the 6th of July, this time alone, and returned on the 27th of July. The rate at which she rose in public estimation, from the reports of her behaviour on these two cruises, was marvellous. It must still be fresh in the memory of every one. Naval officers of all grades were loud in her praise, and she rose at once to be talked about as the crack ship in the fleet.

Two days after she arrived at Portsmouth from her second cruise, Mr. Barnes, one of the Constructors of the Navy, conducted an experiment for finding her centre of gravity. Mr. Reed had resigned the position of Chief Constructor a few weeks before this took place, and his duties had devolved upon a Council of Construction, composed of Messrs. Barnaby, Barnes, and Crossland, formerly his assistants.

We must glance for a moment at the position, with regard to the *Captain*, occupied by this new Council of Construction. Their conduct is, to our mind, one of the most interesting, as well as important, features connected with that sad event. Up to the time of conducting the experiment for finding the position of her centre of gravity they had had, so far as appears, practically no connection with her. Neither had they ever reported upon her favourably or unfavourably. The facts known previous to this experiment were that Messrs. Laird had calculated the position of her centre of gravity before the ship went to sea at all, and that they were satisfied with her behaviour. It was also known that the *Captain* was rather stiffer under her canvas than the *Monarch*.

This being so, the mere finding of the height of the centre of gravity of the *Captain* for comparison with other known ships, which is all that was proposed by Messrs. Laird, and in accordance with their own previous practice, would have told them nothing new, and such a comparison if made would have been misleading. Had Messrs. Laird received this result twelve months before it would have been absolutely worthless to them in determining the degree of safety of the ship if they had used it in the way in which their evidence shows them to have used their estimated position of the same point, which it appears agreed with the result of the experiment. This is a very important consideration, and one to be kept steadily in view when charges are made of criminal sacrifice of life because the centre of gravity had not been found from experiment, as soon as the ship reached Portsmouth. If simply finding the position of the centre of gravity had been all the calculations made, the cause of the loss of the *Captain* would still have been buried in doubt and obscurity.

The further calculations resulting in a curve, showing the stability of the ship at all inclinations between the upright and upsetting positions, which were instituted by the Council of Construction, were such as had never before been performed, so far

as we can discover, for any ship afloat. Six days after the experiment was performed (4th August) the ship left for sea again. Nothing can show more clearly than this, that although she was inclined at Portsmouth, this was not done from any apprehension for her safety. In fact, so admirably had she behaved in the very heavy weather which she had encountered, that every vestige of opposition to her on the score of behaviour and seaworthiness seems to have disappeared.

On the "curve of stability," to which we have alluded, Mr. Barnes had to report on behalf of the Council of Construction. This "curve of stability" showed that at 20° inclination the ship would make her greatest effort to right herself. Beyond that point her effort became weaker and weaker, until at 40° inclination it was extinguished, so to speak. This does not appear to have referred to the *Captain* as she actually was when cruising, but when in a worse condition. An assumption had been made that the poop and forecastle were so damaged as to render them useless. The *Captain*, when she was lost, had her greatest righting force at 21° inclination, and did not lose all effort to recover herself until she had gone over to 54½°. This was explained by Mr. Barnaby at the court-martial, but it has not wholly removed the confusion which the two sets of figures had created. The report of Mr. Barnes was based upon the worse case, and in connection with that we propose to consider it. It would be doing a great injustice to judge this report by the light of facts which have become known since the loss of the ship. We must endeavour to forget for the moment the great stride we have all made in knowledge since that sad event. It must be remembered that for no ship which had yet been to sea had a "curve of stability" been constructed. There was, consequently, no experience to refer for guidance to in judging of any ship's behaviour by the light of her "curve of stability." The difference between the amount of stability of the safest and most dangerous ships was simply one of degree. Without any experience, it would be simply impossible to draw a line at which unsafety ended and safety commenced. To try to do so would seem to us like an attempt to apply an empirical formula to practice without knowing the constants. All ships, after their decks are immersed a small distance, have a diminishing stability. This was known

before the loss of the *Captain* by a few, probably by the Constructors. It is not yet known generally. The want of knowledge such as this is what leads people to think that if they had once seen the *Captain's* "curve" before she went down, they would have been able to have foretold her loss. Any ship's "curve of stability," by a manipulation of the scale on which it is drawn, could, however, be made to produce an exactly similar effect upon the mind of a casual observer.

We are far from saying that it would not be criminal to build and send to sea a full-rigged line-of-battle ship which would be unstable at 40° inclination, and whose rolling propensities were unknown, with a daring captain unaware of the fact, and under no restriction as to the amount of canvas he should carry in rough weather, save the strength of his spars; especially when it is known that she is to engage in exciting sailing races against a rival. It is quite a different thing, however, to condemn a ship as unsafe, which will right herself up to 40°, has been to sea, gained the confidence of all the officers of the fleet, shown that even in very heavy weather she does not roll, and whose captain declares, as we shall presently see was so in this case, that he cannot get her to heel over to more than 6°.

When Mr. Barnes made his report the *Captain* had been to sea, and had gone safely through very heavy weather, notably on one occasion when the storm was considered more severe than on the ill-starred night off Finisterre, by several naval officers who passed through both. In these storms she had never rolled heavily. Here was one well-established fact on which to base arguments in discussing her safety. The other essential point was the amount of canvas which she carried. Calculation on this point, if the ship had never been to sea under canvas, would have been resorted to as a matter of course. But such calculations are unsatisfactory, because the amount of sail which a ship carries is continually changing according to the change of weather. This variation of the spread of canvas is entirely under the control of the officer in command of the ship, who regulates it according to his knowledge and experience as a seaman. The obvious source from which to obtain reliable information on this point was to look at the result of previous experience with the ship at sea.

According to all the accounts which we have been able to

consult we find that when under sail she heeled over to about six or seven degrees. It appears from the evidence of Mr. Barnes before the court-martial, that in a conversation which took place between him and Captain Burgoyne on board the ship, on the day the experiment was performed for finding her centre of gravity, the latter said, "This ship is not difficult to get over to six degrees, but beyond that she will not go." The ship was at that time inclined over at that angle by a certain weight of ballast which had been moved from one side of the deck to the other. Mr. Barnes told Captain Burgoyne that if twice the amount of ballast had been moved across the deck it would have heeled the ship quite twice as much. Mr. Barnes knew also that if when the ship was sailing at six degrees inclination, Captain Burgoyne had doubled the amount of canvas, the same effect would have been produced and the heel doubled.

We regret that Mr. Barnes confined himself in this case to simply answering the question put to him by the court. No one who has thought seriously over the whole question can fail to believe that when he came to report on the curve of stability, he must have attached great weight to this conversation with her captain only six days before he proceeded to sea. The significance of these words of Captain Burgoyne has scarcely been realised. They imply clearly that he never trusted his spars with a greater strain than would be produced on them by a spread of canvas which would heel the ship over to six degrees. We are unable to attach any other meaning to them.

The only facts, then, of importance on which Mr. Barnes' report could have been based (so far as we can judge from the published sources within our reach) may be stated as follows:—The ship had been for two cruises besides her passage from Birkenhead to Portsmouth. She had met with severe weather on several occasions, and she had passed through one very heavy storm. All this time she was watched by admirals, captains, and officers of all ranks in the service, who united in admiration of her behaviour, and their opinions were echoed all over the country by daily newspapers. She scarcely rolled at all. Her captain could not get her over with the canvas and spars at his command beyond about six degrees.—So much for six months' experience, seamanship, and actual trial at sea in rough weather, the whole being backed by a very strong public opinion.

Now for theory, science, and figures. After one half-day's experimenting upon the ship in still water at Portsmouth, in which he only inclined her to six degrees, Mr. Barnes returned to Whitehall. Three weeks after he had the following facts before him in the form of a curve of stability:—The ship's stability increases up to fourteen degrees inclination in proportion to the inclination—that is, if the heel is doubled the righting force is also doubled. At fourteen degrees heel the edge of the deck is at the level of the water. Her stability goes on increasing up to twenty degrees inclination—not so fast as it did before, however. After passing twenty degrees the righting force begins to diminish, and continues to diminish more and more rapidly until at forty degrees inclination it vanishes altogether. Beyond this she cannot right herself even if there is no pressure of sail on her.

Now let us attempt from the above to reconcile theory with experience. Science says, "Forty degrees is not a very large angle for a ship to be on the brink of capsizing at; many ships have been over on their beam-ends and righted themselves after." Experience replies, "But the *Captain* does not roll." Science adds, "A pressure of sail which would heel her to twenty degrees would blow her completely over." Experience says, "But the *Captain* does not carry one-third enough sail for that. Her captain says he can never get her over beyond six degrees." Science, making one more effort, suggests that in squally weather, and in the event of the ship rolling, certain concurrent circumstances may take place which may upset her. Experience replies that "in rough weather the ship has been found not to roll; all naval officers who have seen her at sea consider her perfectly safe, and never anticipate her getting over to angles approaching forty degrees' roll one way. The concurrent circumstances which may happen are too vague and uncertain to attempt by their means to overcome such a weight of naval authority, as, after all, they may be reckoned among the remote contingencies to which all ships are liable. If the ship had never been to sea, and in rough weather, if we did not know her freedom from rolling, we might well have apprehension, but facts must not be lost sight of; she has been tried, and her seaworthiness is an accomplished fact." Science admits that after the result of her trials it does not seem as if she would capsize, and takes refuge in the inquiry why this should be the case.

On the strength of reasoning, the process of which we shall probably never know, but which from the nature of the task must have resembled the above, the Constructors of the Navy concluded that the ship was "not unsafe," and Mr. Barnes's report went forward on the 23rd August. In little less than a fortnight from the date of this report (the night between the 6th and 7th September) all their reasoning was blown to the winds by the ship capsizing. Directly the report of the loss of the *Captain* reached them they must have felt how treacherous was the reliance to be placed upon the testimony of naval officers regarding the seaworthiness of their ships. But who, before the event, would have placed reliance upon figures when contradicted by naval experience at sea respecting the behaviour of a ship which had been tried in a storm, even though Mr. Barnaby had successfully opposed the introduction into the service of the *Duncan* sailing monitor on scientific grounds, when no experience with such ships existed to influence him?

Had this curve of stability been in existence before the ship went to sea at all, it can hardly be doubted that apprehensions for her safety would have been excited, and the ship would probably have been detained for harbour service. But on whom did the duty of constructing it devolve? Was it not a portion of the work of designing her?

In looking at the evidence which has come to light since the loss of the ship, we find the startling fact that she was sailing at an angle of heel of 14 degrees when Admiral Milne was on board of her the last day on which she was seen. This single piece of evidence, to any one who has examined the curve of stability, is nothing less than astounding. Every one on board the ship the whole of that day may be well said to have been "hovering on the brink of eternity." To say nothing of the blows of the sea, it is an indisputable truth, that if the wind had at any time ceased for a few moments until the ship had got upright, and then been renewed suddenly at the same strength as before, it would have capsized her at once. There has been no satisfactory explanation given for the ship's being inclined so much on this day. It was adverted to at the court-martial, and the suggestion was made that there may have been water in the ship. This, however, we can hardly believe to have been the case, to any great extent, without its becoming known.

We find ourselves in this dilemma, that unless we come to the conclusion that Captain Burgoyne had grown in boldness and confidence with such rapidity that he carried more than twice the press of canvas on this than on any former cruise, we are unable to account for the phenomenon observed by the admiral when he was on board. Had this state of things been contemplated by the Constructors, we do not doubt for a moment that they would have pronounced her in hourly danger of capsizing.

To give an illustration of this we will take the case of the *Monarch*, using the following official information respecting her and the *Captain* which has been published recently.

	Monarch.	*Captain.*
Angle at which the edge of the deck is immersed	28°	14°
Amount of righting force in the above position in foot-tons	12,542	5,700
Angle of maximum stability . . .	40°	21°
Maximum amount of righting force in foot-tons	15,615	7,100
Angle at which the righting force becomes zero	69½°	54½°
Reserve of dynamical stability at an angle of heel of 14 degrees in foot-tons . .	6,500	410

The best measure of the comparative power of the two ships to resist upsetting, after a given angle of inclination is reached, is to be found in the dynamical stability. This is seen to be at an angle of permanent heel of 14 degrees—nearly 16 times as great in the *Monarch* as it was in the *Captain*. In other words, if both ships were inclined, under sail, at the angle which immersed the edge of the *Captain's* deck, the reserve of energy to prevent upsetting by a squall would be in the two ships in the proportion of 16 to 1.

We know that the *Monarch* does not heel under her canvas to 14 degrees. Suppose, on the strength of that knowledge, we pronounced her to be a safe-sailing ship, and shortly after doing so we heard that she was sailing in a heavy sea off Cape Finisterre under a press of canvas which heeled her to 28 degrees,—we should immediately change our opinion, and say she was in great danger. In fact the whole problem as to what ship is safe and what ship is not, resolves itself into one of degree. To solve it properly will require the careful study of men well grounded in the principles of naval architecture. The true lesson of the loss of the *Captain*

is to be learned by carefully considering all the circumstances which tended towards that end—not by blindly rushing for safety to the directly opposite type of ship, and perhaps paving the way for some other unforeseen calamity. The danger of capsizing to which low-deck ships are liable was first pointed out by Mr. Barnaby, and we confidently leave in his hands, and in those of his colleagues, the difficult and responsible duty of determining its limits.

The paragraph which we have quoted above has been rendered somewhat famous by the blunders it has caused its critics to make. One of the weekly papers came out with a stirring article, pronouncing the latter portion of it simply claptrap, and in attempting to prove this statement displayed its wisdom, and justified the moderation of its language, by confounding statical foot-tons with dynamical.

Probably the most absurd, however, of all these amateur criticisms was contained in Admiral Gardiner Fishbourne's letter on the subject to the *Standard.* This letter, written in a tone of outraged common sense, says that any schoolboy who made such a blunder would be put to the bottom of his class. He then shows that he also is not able to distinguish between statical and dynamical foot-tons, and by applying one theory to the *Captain* and another to the *Monarch,* he makes the proportionate reserve stability 5 to 1 instead of 16 to 1. Yet Admiral Fishbourne is a writer on naval architecture, and is the author of a scientific pamphlet on the loss of the *Captain!*

It is for such reasons that we wish to warn any of our readers unacquainted with the technical portions of the subject against mistaking the indiscriminate jingling of scientific terms for wisdom. Those who are free from this danger will not need warning against being led away by irrelevant nonsense from bestowing a due share of attention upon the serious questions yet to be answered concerning the loss of the *Captain,* and their effect on the future of our Navy.

I.

ON THE LIMITS OF SAFETY OF SHIPS AS REGARDS CAPSIZING.

By C. W. Merrifield, F.R.S., Principal of the Royal School of Naval Architecture and Marine Engineering.

If we consider a ship heeling over in still water, and have regard simply to the statical effects of the pressure of the water and the action of gravity, we observe that these effects are the same as would be produced by a pair of parallel and equal forces. The force of gravity may be replaced by a single force acting downwards at the centre of weight of the ship, and the pressure of the water by a single force acting upwards at the centre of figure of the displaced water, or centre of buoyancy. These forces therefore constitute a *couple*, the axis of which is in the direction of the vessel's length; the arm is the horizontal distance between the centres of weight and buoyancy, and the moment is the product of this arm into the weight of the vessel, or, what is the same, into the weight of the water which it displaces, called the displacement. The question whether this couple is an upsetting or righting one depends upon the centre of buoyancy moving out from the middle line plane slower or faster than the centre of weight. With a ship which has both sides alike, these are in the same vertical line when she is upright. The determination of their motion, as the ship heels, is one of pure geometry. For the present we are only concerned with its effects. Whatever may be the details, the instant after the centre of weight has overtaken the centre of buoyancy in moving out towards the direction of heeling, there is a tendency to upset, even without any extraneous force, such as that of the wind.

The action of a steady wind, after all oscillations have disappeared, and steady motion has been obtained, consists partly of linear motion of the ship and partly of another couple, formed by the resistance of the water to the lateral motion of the ship, as one force, and by the resolved pressure of the wind on the sails as the other. This wind-couple, if the vessel maintains a steady inclination, must be exactly equal to the righting couple due to the stiffness of the ship; for if we have regard only to the tendency to capsize, or the reverse, we need only consider the resolved wind-couple acting in a plane parallel to that of the stiffness-couple. The statical measure of either of these couples is its moment, expressed in foot-tons, or some equivalent unit.

The knowledge of a ship's statical stability at any particular angle is not sufficient to determine the practical question of her capsizing. Dynamically, the difference between the moments of the wind-couple and the stiffness-couple is simply an accelerating or retarding force. Even in smooth water, the effects of a varying wind, or of the sudden application of a steady wind, as may happen when a vessel passes a high headland, depend upon the equation of work, not on the vanishing of the applied couple.

Let us suppose that we have calculated the moment of the righting couple for all possible angles of inclination, and that, setting out equal angles at equal distances along a base line, we set off the corresponding moments as ordinates. We then obtain the curve of stability or stiffness. I will suppose it to be as in the accompanying diagram :—

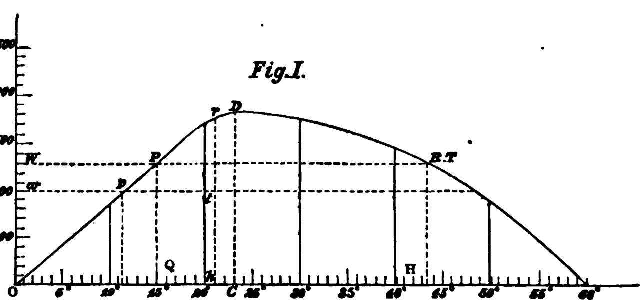


Fig. I.

The ordinate, always beginning from zero, is here supposed to reach its maximum at 23°, when the stiffness is 1,850 foot-tons; and the stiffness vanishes at 60°. At this point there is unstable equilibrium, and if the vessel be *slowly* pushed beyond it, she must continue to heel until she reaches another position of stable equilibrium. If there be such a position, short of her being bottom up, she is said to be "on her beam ends."

Now consider the vessel to be suddenly exposed to the action of a steady breeze, producing an upsetting couple of 1,000 foot-tons. This wind-couple will be in excess of the righting couple until 11° 30′ of heel. It will then be balanced by the righting couple; but the vessel will not stop at that point, because it will have accumulated a quantity of mechanical work, represented by the area of the triangle O *w p;* it will continue to heel, with diminishing velocity, until this work has been expended by the action of the righting couple in excess of the wind-couple. This will take place at about 21° of heel, when the area *p t r* is equal to the area O *w p*, or, what is the same thing, when the total work done by the wind, represented by the rectangle O *w t h*, is equal to the total work done against it by the righting couple, represented by the area O *r h*. The vessel will then begin a return oscillation against the wind, the applied force with which it tends to return being then measured by the line *t r*.

Suppose now that the steady pressure of the wind-couple is 1,300 foot-tons, and that the wind is again suddenly applied, the applied couple will vanish when the angle of heel is 15°, but the vessel will continue to go over beyond this until the area of the rectangle O W T H is equal to the curvilinear area O P D R H. The righting force against the wind will then be represented by the line R T, and since the points R and T are here coincident, their force vanishes, and there is nothing whatever to right the vessel. Therefore, although her statical stability does not vanish until 60° of heel, a wind which would give her a steady

heel beyond 15° would capsize her if it came as a sudden gust.*

Through what follows, I neglect the diminution of the effect of the wind on the sails, by the vessel's heeling. This is not sensible until very large angles are reached, especially when bellying of the sails is taken into account. Besides this, the reasoning involves several assumptions which are not in accordance with observation, and it omits others, which ought not to be neglected.

We assume that the displacement remains invariable, and we neglect all keel resistance and friction. Evidently, if part of the work done by the wind be taken up by these obstructions, the result will be more favourable for the vessel. Again, we assume the gust to be suddenly applied—that is, bursting suddenly from a calm into its full force, and lasting long enough to upset the ship. Now this is quite contrary to what we know of the propagation of atmospheric waves, especially away from the coast. Therefore the work done by the wind should be represented, not by a rectangle, but by a

Fig. II.

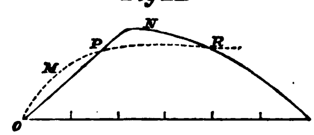
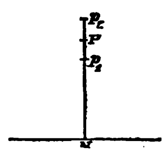


Fig. III



curve beginning from O. Thus, the curve of stability being given by the plain line in Fig. II., the wind curve would be given by the chain line, and safety would depend upon the area O M P being less than P N R.

On the other hand, we have entirely neglected the effect of waves. These will sometimes tend to right the ship, and sometimes to upset her. In considering the limit of safety we must take the worst case.

In a stormy sea, with waves, the *statical* stability of a

* According to the data stated at the court-martial, this would have happened at 13° with the *Captain*.

ship may be supposed to oscillate about the calm-water stability or stiffness. Thus for a particular amplitude of wave motion we may have something of this kind:—N P (Fig. III.) being the righting moment for still water, this moment will oscillate from N p_1 to N p_2 in wave water. We have no means of calculating what this oscillation may be, because it depends upon the mechanical composition of the wave as well as on the geometrical form.

Of course, if a ship lurches beyond her proper statical heel, the curve of righting moments in wave water will oscillate about the still-water curve like Fig. IV., which, however, represents only one particular combination of phase between the

Fig. IV.

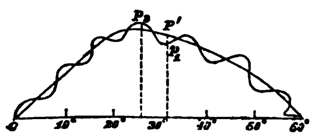
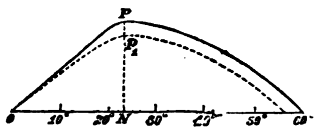


Fig. V.



wave and the lurch. But if we could draw all the curves corresponding to every variety of phase, we should obtain a belt, the inner edge of which (envelope of the different oscillatory curves) would give a limit within which none of them would pass. If we then apply to this curve the construction first used, we shall obtain an inferior limit to the capsizing angle—that is to say, a limit of heel short of which the righting moment will still exceed the upsetting moment of the wind-couple. But we have no means at present known of setting off the curve O p, and the object here is simply to call attention to the fact that it must lie within the curve O P, and *considerably within it* in very rough water.

This includes the rolling of the ship, so far as relates to the angle which she will bear without risk of capsizing. But it has no reference at all to the dynamical stability, or stored work, inasmuch as the phase of the wave does not remain unaltered during the period of heeling. Evidently the accumulation of work depends on the individual curve, and its limiting conditions are not to be inferred from the envelope of the family of curves.

Reverting to Fig II., we conclude, that for the curve O P N R, we must take, not the curve of stability given in Fig. I., but the inner curve of Fig. V.

It follows that the angle at which the statical stability altogether disappears may very easily be three or four times the angle of safety due to the wind measured statically. That is to say, in a stormy sea, it is conceivable that a vessel might capsize with a gust equal in force to a steady wind which would heel the vessel 15°, while yet the statical stability would not vanish until an angle of 60° was attained. For small angles a sudden gust pushes a vessel to double the statical angle; but for critical angles the statical angle has to be considered at both ends of the curve of stability. Moreover, although there is no such thing practically as an absolutely sudden gust, yet the gradual increase of the wind may be much more than compensated for by the possible diminution of stability due to the waves.

ACCIDENTS IN SHIPBUILDING AND LAUNCHING.

THE year 1870 will be long remembered by all who take any interest in our navy and mercantile marine, as one of a very disastrous character to our sailors and shipbuilders; calamities, both by sea and land, of a most distressing and startling nature having taken place. The one which has occupied the public mind more than any other is the deplorable loss of H.M.S. *Captain* at sea, by capsizing; nor has the public spared the designers of this unfortunate ship for neglecting, as they allege, those theoretical principles which should have guided them in her construction, and thereby have prevented such a lamentable catastrophe.

Scarcely, however, had we recovered from this shock, than the news of another disaster reached us. This time it is on land. A screw ship, between 600 and 700 tons burden, in progress of building at Low Walker on Tyne, tumbles off the stocks and crushes seven men beneath her to death, besides wounding several others. What shall we say to the cause of this calamity? Surely it calls for some redress, for although it is not one of such magnitude and national importance as that of a ship with 500 souls on board upsetting at sea, it nevertheless demands some attention from the managers of our shipbuilding firms. For such an event to happen in this professedly shipbuilding country, unaided by any extraordinary phenomenon, either in earth or air, is so appalling that we cannot denounce too strongly that recklessness which is so prevalent in some of our merchant shipbuilding yards. Why, we ask, should men's lives be so jeopardised, when with ordinary care and proper supervision, dangers such as we are here referring to might be averted? And it is because we fear that accidents like the one above mentioned will be constantly occurring, that we are induced to write this article; in fact, another has already taken place since the one we have alluded to happened. A steamer at

Sunderland tripped her blocks in the night, and took a leap in the dark, and it was a most fortunate circumstance that she did not perform this freak in the daytime, for had she done so, in all probability the men employed on her would have shared the same fate as those at Low Walker.

We could mention several other cases which have come under our own observation, showing that these casualties are by no means uncommon; and, in our opinion, a great deal of ignorance exists with regard to the system of laying the blocks for a ship to be built upon, else why so many mistakes? It often happens that when a ship is brought into a state for launching, difficulties have to be overcome that were never contemplated, because certain rules which ought to have been regarded were never even thought of or understood, for if they had been we should not have witnessed so many failures.

Some of the so-called foremen in the merchant service remind us of Robinson Crusoe and his boat, which, after he had made it, he was not able to launch into the water. He says of himself, "I went to work upon this boat the most like a fool that ever a man did who had any of his senses awake; not but that the difficulty of launching my boat came often into my head; but I put a stop to my own enquiries into it by this foolish answer which I gave myself: 'Let me first make it, I'll warrant I'll find some way or other to get it along when it is done.'"

Now we happen to know that ships have been built on blocks too low, so that when the time for launching has arrived the necessary declivity could not be obtained. On the other hand, ships have been built on blocks too high, so that the launching-ways could not be extended far enough into the river to float them properly.

Again, ships have been built on blocks with their upper surfaces laid with too much declivity to insure safety while building and success when launching; while others have been built on blocks with too little declivity, owing to the shallow draught of water at the end of the ground-ways.

We have also known vessels to be built on blocks with their upper surfaces laid to the same declivity as the launching-ways. This is also objectionable, as with this arrangement you lose the advantage of holding the ship on the day of launching; for by having a few blocks left under the vessel's forefoot, the caps of

which need not be split out until a few minutes before the dog-shores are knocked away, they immediately bring her up—*i.e.*, obstruct the downward tendency of the ship—should she be inclined to draw.

Again, a ship has been known to bump her forefoot on the sill of the slip at the time of launching so violently as to cause her to sustain serious injury. This also must be attributed to a want of foresight in determining the height of the foremost block upon which the ship has been built; for not only is it necessary to have it high enough for the men to perform their work under the forefoot, but also to clear the lower end or sill of the slip. Now, as the declivity of the launching-ways is generally greater than the incline given to the foundation of the slip, an allowance must be made for this difference, and the foremost block must be raised accordingly, in order that the forefoot of the ship should clear the sill of the slip about 9 inches; for it is well known that two lines not being parallel to each other will meet if extended; and on the same principle, if a ship be launched down a greater incline than the one upon which she was built, although there may be plenty of clearance when she begins to move, yet by the time the forefoot of the ship reaches the end of the slip the two may come in contact, unless proper means be taken to prevent it.

Blocks are often laid or placed too far apart, having sometimes as much as eight feet distance between them; whereas we consider that they ought in no case to be more than five feet apart; but the class of ship must determine the distance. They are also frequently laid in the most slovenly manner possible; pieces of balk timber simply piled one upon another, without any trimming or faying of the surfaces, being adopted. This has been the rule in some yards we could mention, and the consequence has been that the blocks, instead of being firm, have been rickety. There is also another fault that has come under our observation, *i.e.*, the careless manner in which the blocks are erected with regard to their standing upright; for instance, the workmen are allowed to depend upon their eye alone for this, instead of using a plumb to guide them, and it often happens that the men get deceived, and blocks are frequently to be seen with their heads inclined down the slip. Again, in those yards we have been referring to, how seldom do

we see spars fitted between the blocks to prevent their tripping! so that really we have here all the elements necessary to produce a similar tragedy to that at Low Walker; and there can be but little doubt that it is this scamping of the work that has led to many other such disasters; and it would appear that this dangerous practice of working is to be apprehended more in those yards where the system of piece-work has obtained its full development than in others. We say that the men ought never to be allowed to act in this suicidal manner; many of them are not even aware of the danger they are exposing themselves and others to. The method of laying blocks for building ships is so well described in a work, entitled "Shipbuilding, Theoretical and Practical," edited by Professor W. J. M. Rankine, that if the reader wishes for further information upon this subject, he can there obtain it. We would, however, add, that to render a ship safe during the time of building, shores should be placed both against her sides and stern, in a fore and aft direction, the side-shores should be placed in position as soon as the midship body is in frame, as they will keep the frames in their proper positions vertically, and also check the downward tendency of the ship, for there must always be a force exerted in this direction when a ship is perched upon blocks several feet in height, and on an incline; bilge blocks may also be used with advantage.

Lastly, the foundation of the slip must not be neglected. Too much care cannot be given to this, as without a firm foundation, we cannot answer for the ship being properly built, or successfully launched; but of course the class of ship intended to be built, must in a great measure determine this. In the case of an iron-clad ship, we have no hesitation in saying that piling should be resorted to; but in whatever way it is formed, care should be taken to insure it being of one uniform solidity, for unless this precaution be taken, it is not at all certain that the launch will be successful. Ships have been known to stop half-way down the ways, and in some cases have broken their backs, owing probably to the weight of the ship when transferred from the keel blocks to the launching ways having produced unevenness through certain parts of the foundation being less consolidated than others, causing the grease between the two surfaces of the ways in launching to exude more freely at some places than

at others, whereby the ways fire in consequence of the friction thus produced.

The same reckless manner of conducting work during the progress of building is also to be seen at the time of launching a ship, and this ought, above all others, to be a time when every precaution should be taken to ensure success, and especially to guard against loss of life and limb. We will give an instance of what we mean. Some time ago we paid a visit to one of our merchant shipbuilding yards on the day when a ship of 1,000 tons burden was to be launched. It was about one hour before the appointed time; every block had been removed from under her keel, and the dogshores alone were holding her on a greased incline of $\frac{7}{8}$-inch to a foot, and when we expostulated with the foreman in charge for being so venturesome, asking him if he were not afraid of an accident, he coolly replied, "We have been trying for years past to get an accident, but cannot." Fortunately, in this case, the ship went off all right. But a few months afterwards we heard of another launch from the same yard, and for aught we know, under similar circumstances. This time the ship ran away one hour before it was intended, injuring several people and damaging herself, so that we suppose the thing this foreman had been trying for years to bring about, was on that day accomplished. Now, it strikes us that there was a great deal of ignorance mixed with this boasting, and that really this individual did not know to what we referred when we spoke of avoiding danger by not removing all the blocks from under the keel of the ship.

We were once present at a launch where we noticed that the bilgeways were made up in three pieces, without any connections at their butts to prevent them parting asunder lengthwise. The signal was given to knock down the dogshores, but as the ship was drawing at the time, the starboard one refused to yield to the blows struck with a heavy maul, and the consequence was that before it could be cleared away the ship went away with a crash, pushing out the whole of the foremost portion of the cradle on the starboard side; she, however, continued her downward course in nearly an upright position until she became water-borne at the stern, when she immediately turned on her beam-ends, causing intense excitement among all present; thanks,

however, to the position of her centre of gravity, as the ship became more immersed, she righted herself; but what the consequence would have been had she been an iron-clad, we shall leave our readers to conjecture. This ship was about 1,000 tons burden.

Another case of a similar nature occurred some time afterwards through the aftermost poppets not being properly secured at their heads, so that when the ship was about two-thirds the distance down the slide those on the port side gave out, which caused the ship immediately to turn on her side, throwing several people overboard; but to the astonishment and gratification of all present, she also righted herself, otherwise many lives must have been sacrificed. These last two accidents occurred on the Thames.

In calling attention to these events we can only hope that they will serve as so many beacons to guard against future dangers; and in saying this we do not wish it to be understood that we think accidents under all circumstances can be avoided, for we know that in the best-regulated yards disasters will sometimes happen over which one has no control. Ships at the time of launching have refused to move, from some inexplicable cause, notwithstanding all the available force that could at the time be brought to bear upon them; and, on the other hand, they have gone off before their time, when every effort has been made to prevent them.

Our space forbids us entering upon the subject of minor accidents in shipbuilding, otherwise we should like to have referred to a few of these, as they are becoming daily more frequent.

W. B. B.

ON THE STRENGTH OF CRANK SHAFTS.

BY W. C. UNWIN, B. SC., INSTRUCTOR IN MARINE ENGINEERING TO THE ROYAL SCHOOL OF NAVAL ARCHITECTURE AND MARINE ENGINEERING.

THE calculation of the strength of the parts of steam-engines is generally made on rather arbitrary and unsatisfactory assumptions. In the case of the crank-shaft, for instance, it is quite usual to assume that the steam acts with full initial pressure throughout the stroke, to neglect the obliquity of the connecting-rod, and to assume either that the shaft is most strained in that position in which the twisting moment is greatest; or, more roughly still, to assume that the stresses are proportional to the mean twisting moment. On the other hand, if we attempt to take account of the variation of steam pressure, due to expansion and compression, the difficulty is encountered that that variation is discontinuous, obeying one law during the period of admission, a second during the period of expansion, a third during the exhaust, and a fourth during compression. Further, in consequence of the obliquity of the connecting-rod, the variation of pressure on the crank-pin is different in the forward and backward stroke, and, for a pair of engines coupled at right angles, the complexity of the problem is again doubled.

In calculating the stresses on propeller shafts, Professor Rankine has taken into account—(1.) The excess of the maximum over the mean twisting action due to the varying position of the crank or cranks. (2.) The bending action of the weight of the shaft. (3.) The bending action of the reaction due to the pitching and heaving of the ship, which is proportional to, and varies from one-eighth to one-fourth of, the bending action of the shaft's weight.

In the case of a crank-shaft, the weight of the shaft, and consequently the reaction due to the motion of the ship, produce a less proportionate influence than on the propeller-shaft, in consequence of the much greater proportion of the diameter to span.

In an ordinary case, the intensity of stress, due to the bending action of the weight, would be about one-fourth as great in a crank-shaft as in a propeller-shaft of a pair of marine engines. There is no difficulty in taking the weight into account; but, for simplicity, it will be neglected in the following investigation.

The principal straining actions on the crank-shafts of engines (which for definiteness we may suppose to act horizontally) are —(1.) The horizontal force, equal to the effective load on the piston at each point of the stroke. (2.) The horizontal reaction due to the variation of velocity of the piston, piston-rod, connecting-rod, and other attached parts. (3.) The vertical force due to the obliquity of the connecting-rod, and varying also with the resultant of the horizontal forces. There is also a vertical reaction due to the swaying of the connecting-rod, but, except in calculating the strength of the connecting-rod itself, it does not produce an effect large enough to need to be taken account of.

In regard to the influence of the horizontal reaction, it requires to be noted that, in starting or stopping, every engine passes through all gradations of velocity from zero up to a maximum limit. Hence the horizontal reaction may vary from nothing up to the amount due to the greatest velocity at which the engine runs. And since the steam pressure is greatest at the beginning and least at the end of a stroke, and the reaction acts against the steam pressure at the beginning and with it at the end of a stroke, cases arise in which the crank-shaft is most strained when the engine is at full speed, and others when it is moving so slowly that the reaction may be neglected; and in any given case it requires to be determined whether the reaction adds to or lessens the straining action.

As the problem thus presented is too complex to solve in a general manner, it appeared that an accurate examination of one particular average case would furnish useful information as to the conditions under which the stresses in the crank-shaft reached a maximum. To that end indicator diagrams were drawn for an engine having cylinders of 80 inches effective diameter, 42 inches stroke, working with steam of 35lbs. absolute initial pressure, and cut off at full-stroke, at half-stroke, at quarter-stroke, and one-eighth stroke. The clearance was taken equal to 3 inches of the cylinder length, and the back-pressure

at 3lbs. Compression was assumed to begin at seven-eighths stroke. The direction of revolution is shown in fig. 1, p. 66. These diagrams correspond to the following data:—

	Mean effective pressure. lbs.	Ratio of mean to initial effective load on piston.	Ind. H. P. One engine.	Mean twisting moment on crank-shaft; one engine; inch lbs.
Full steam	32·00	1·00	2,456	2,149,000
Cut off at	26·60	·83	2,044	1,788,500
„ $\frac{1}{4}$	19·05	·59	1,449	1,268,000
„ $\frac{1}{8}$	12·64	·39	957	838,000

Initial effective load on piston = (initial pressure − back pressure) × area = 160,832 lbs.

From these indicator diagrams were obtained the horizontal pressures corresponding to sixteen equidistant points in the path of the crank-pin, allowing for a connecting-rod of six cranks length. These are laid off on the upper diagram in Plate I., O X being the axis from which the ordinates are measured. From these horizontal forces, the vertical forces due to the obliquity of the connecting-rod were deduced and set off in the same way on the second diagram in Plate I. The curves of these two diagrams, drawn in full lines, give the horizontal and vertical pressure on the engine crank-pin, for any position of the crank, and for the assumed grades of expansion, in the case in which the engine is moving so slowly that the reaction due to the horizontal motion of the piston, &c., may be neglected.

To determine the reaction due to the horizontal motion of the piston, &c., the crank-pin being assumed to move at a constant velocity of 13·2 feet per second, the tables at the end of Mr. Porter's treatise on the indicator were used. Those tables give the successive intervals of space Δs moved by the piston, for each degree moved by the crank, in terms of the crank radius (r), including the influence of the obliquity of the connecting-rod. Let Δt be the time in which the piston moves through each of the successive intervals Δs_1, Δs_2, then the reaction of the weight of piston, &c. (w) for that position of the crank is,

$$F = \frac{w}{g} \cdot \frac{\Delta s_2 - \Delta s_1}{(\Delta t)^2} r$$

The values of F are given in fig. 3, Plate I. Compounding those values with the horizontal forces due to the steam pressure, we get the dotted curves in fig. 1. Rededucing the vertical forces corresponding to these new values of the horizontal forces, we get the dotted curves in fig. 2. The dotted curves of these two figures furnish, therefore, the pressures on the crank-pin in the case in which the engine is moving at full speed.

To estimate easily the bending and twisting moments on the crank-shaft, it is convenient to reduce these horizontal and vertical pressures to pressures radial and tangential to the path of the crank-pin. This has been done, and the results are recorded in the following tables. But instead of expressing the results in pounds, the ratios of the radial pressure (μ) and tangential pres-

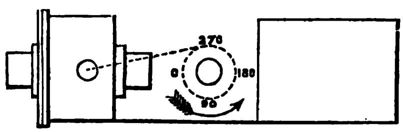


FIG. 1.

sure (ν) to the initial effective load on piston (P) are given. For any engine working in conditions not widely divergent from that selected for examination, the radial and tangential pressures on crank-pin will be μ P and ν P, where μ and ν are the values in

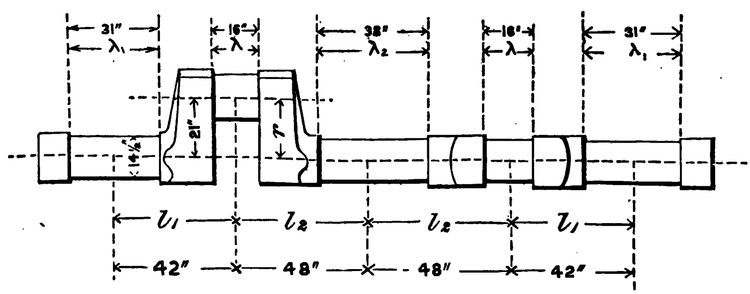


FIG. 2.

the following tables corresponding to the given position of crank and grade of expansion, and P = (initial—back pressure) $\times$ area of piston.

Plate. 1.

FIG. 1.
HORIZONTAL FORCES.

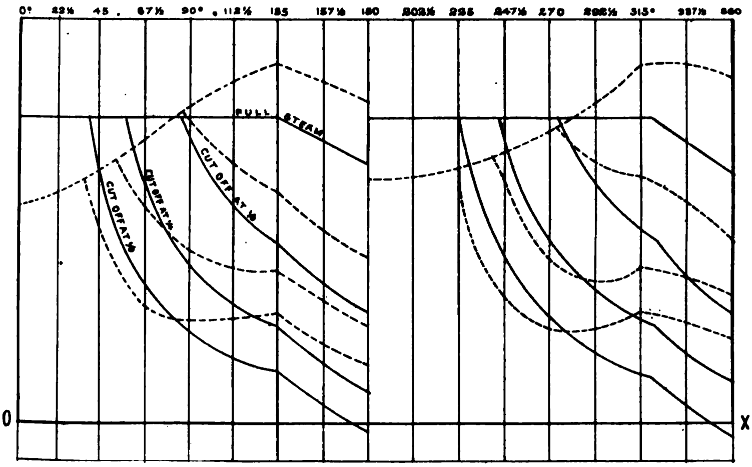


FIG. 2. VERTICAL FORCES.

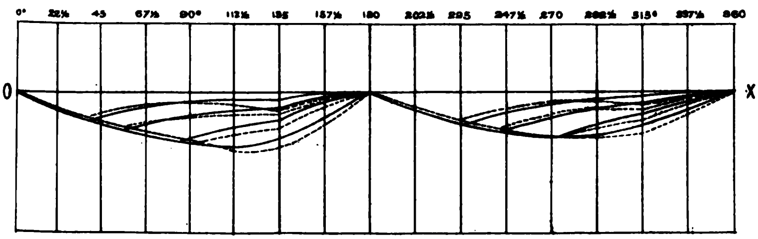
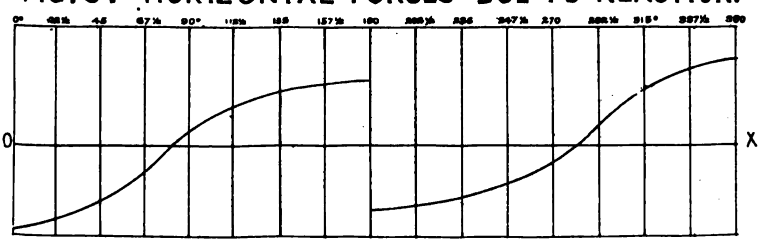


FIG. 3. HORIZONTAL FORCES DUE TO REACTION.



In Figs 1 & 2 The Full curves are the Loads neglecting reaction, and the dotted curves including it.

SCALE ON WHICH UNIT = TOTAL LOAD ON PISTON.

0 ·1 ·2 ·3 ·4 ·5 ·6 ·7 ·8 ·9 1·0 1·1 1·2 1·3 1·4 1·5

BROS: LITH: LONDON.

TABLE I.—*Reaction Neglected.*

Angle of Crank with initial position.	Full Steam.		Cut off ½.		Cut off ¼.		Cut off ⅛.	
	μ	ν	μ	ν	μ	ν	μ	ν
0°	−1·00	0	−1·00	0	−1·00	0	−1·00	0
22½	·90	·43	·90	·43	·90	·43	·90	·43
45	·63	·79	·63	·79	·63	·79	·52	·63
67½	·23	·98	·23	·98	·19	·77	·11	·41
90	+·16	1·00	+·15	·94	+·08	·50	+·04	·26
112½	·52	·86	·40	·60	·19	·31	·09	·15
135	·79	·61	·48	·32	·22	·18	·11	·08
157½	·86	·29	·42	·10	·16	·05	·02	·03
180	·84	0	·32	0	·08	0	−·06	0
180	−1·00	0	−1·00	0	−1·00	0	1·00	0
202½	·95	·32	·95	·32	·95	·32	·95	·32
225	·78	·62	·78	·62	·78	·62	·78	·62
247½	·52	·86	·52	·86	·47	·80	·26	·45
270	·17	·99	·17	·99	·09	·58	·05	·31
292½	+·25	·98	+·15	·77	+·08	·39	+·04	·19
315	·63	·79	·34	·51	·18	·23	·09	·11
337½	·83	·40	·38	·22	·15	·08	·03	·02
360	·83	0	·33	0	·08	0	−·05	0

TABLE II.—*Reaction Included.*

Angle of Crank with initial position.	Full Steam.		Cut off ½.		Cut off ¼.		Cut off ⅛.	
	μ	ν	μ	ν	μ	ν	μ	ν
0°	−·71	0	−·71	0	−·71	0	−·71	0
22½	·66	·32	·66	·32	·66	·32	·66	·32
45	·51	·64	·51	·64	·51	·64	·40	·50
67½	·22	·90	·22	·90	·16	·67	·05	·34
90	+·17	1·04	+·16	1·01	+·09	·54	+·04	·31
112½	·59	·98	·43	·72	·24	·42	·15	·26
135	·93	·73	·60	·47	·37	·28	·24	·18
157½	1·05	·36	·60	·20	·34	·12	·21	·06
180	1·05	0	·54	0	·29	0	·16	0
180	−·78	0	−·78	0	−·78	0	−·78	0
202½	·75	·25	·75	·25	·75	·25	·75	·25
225	·65	·51	·65	·51	·65	·51	·65	·51
247½	·45	·75	·45	·75	·42	·69	·20	·34
270	·15	·94	·15	·94	·08	·53	·04	·26
292½	+·25	1·05	+·20	·82	+·11	·46	+·05	·26
315	·74	·93	·48	·61	·29	·38	·20	·26
337½	1·06	·52	·64	·32	·39	·19	·26	·12
360	1·12	0	·62	0	·37	0	·24	0

Ratio of Mean to Maximum Twisting Moment.

The first useful results to be deduced from this table are the ratios of the maximum to the mean twisting moment. These results are given in the following table :—

—	Single engine.		Two engines at right angles.	
	Reaction neglected.	Reaction included.	Reaction neglected.	Reaction included.
Full Steam	1·57	1·65	1·24	1·24
Cut off $\frac{1}{2}$	1·87	1·90	1·08	1·19
" $\frac{1}{4}$	2·13	1·93	1·40	1·46
" $\frac{1}{8}$	2·59	2·05	1·55	1·64

These values may be used in calculating the propeller shaft. In Plate II. are given the curves of twisting moments for a pair of engines coupled at right angles, the dotted circles showing the mean twisting moments for the same grades of expansion. The relative uniformity of the twisting moment for a cut off of one-half is very striking, and I do not remember to have seen it remarked before. No engines now work with quite full steam, and the reduction of the straining action for a small amount of expansion is therefore important to notice.

Straining Action on Crank Shafts.

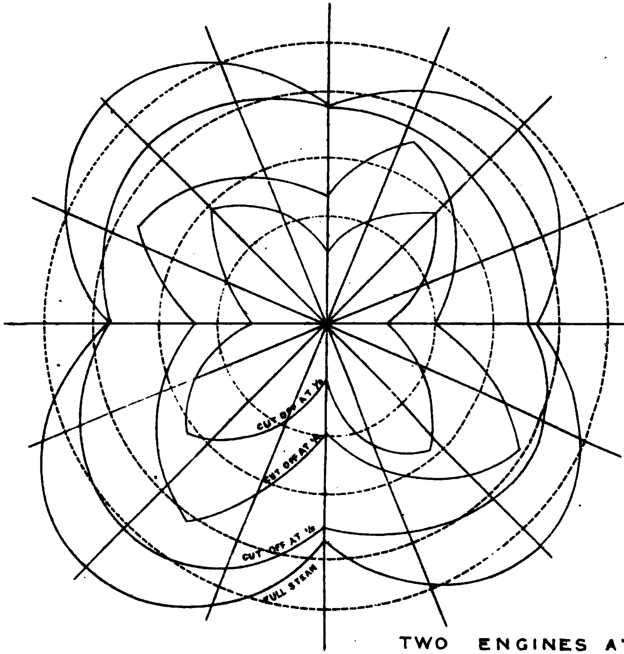
Suppose next that it is required to determine the strength of a crank-shaft. From the tangential and radial pressures, νP and μP acting on the crank-pin, the bending moments M', M'', due to these forces, must be ascertained, and the resultant bending moment will be $= M = \sqrt{(M'^2 + M''^2)}$. Next from the tangential pressure νP we must determine the twisting moment T. The stress produced by these bending and twisting moments will be equivalent to that which would be produced by an ideal twisting moment—

$$T_1 = M + \sqrt{M^2 + T^2}$$

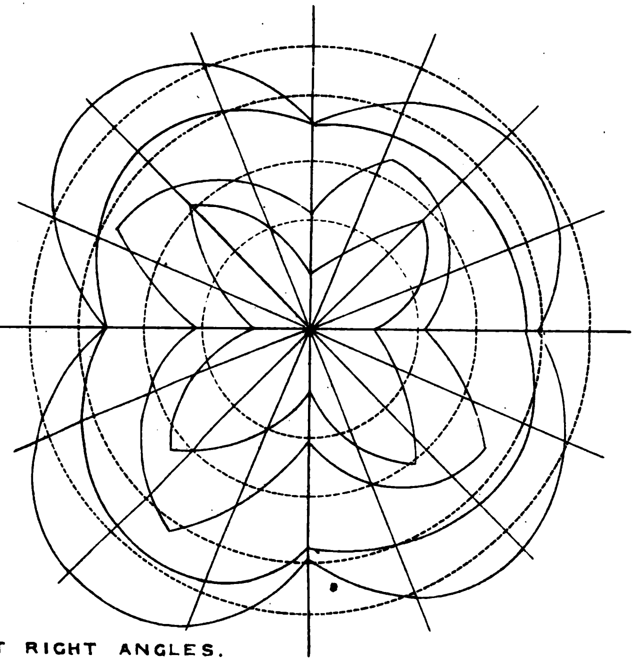
And we ought either to calculate T_1 for a series of crank angles, or to find some criterion of the angle for which it is greatest. In most cases the expression for T_1, in terms of ν and μ, will be

TANGENTIAL PRESSURES AND TWISTING MOMENTS.

REACTION NEGLECTED.



REACTION INCLUDED.



TWO ENGINES AT RIGHT ANGLES.

SCALE ON WHICH UNIT = TOTAL LOAD ON PISTON.

UNWIN BROS: LITH: LONDON.

complicated, but, by the aid of Poncelet's theorems, it may always be reduced to a form simple enough to enable us to discard at sight the greater number of the sixteen crank angles, for which ν and μ have been calculated, and to pick out three or four, amongst which the maximum value is to be sought. The following examples illustrate the method:—

Example 1.—*Crank-shaft for single engine.*—Suppose that the engine works under conditions similar to those for which the values of μ and ν have been calculated. The greatest load on crank-pin is $\sqrt{\mu^2 + \nu^2}$ P, which is nearly equal to 0·828 $(\mu + \nu)$ P. It will be easy to see in the tables which angles give $\mu + \nu$ greatest. For the crank-shaft journal, an approximate value for the distance (l) between the centre lines of crank-pin and shaft journal must be assumed. This is the lever-arm of the bending forces. The bending moment is $= \sqrt{\mu^2 + \nu^2}$ Pl; the twisting moment $= \nu$ Pr, where r is radius of crank. The twisting moment equivalent to these moments is,

$$T_1 = \{ l \sqrt{\mu^2 + \nu^2} + \sqrt{(\mu^2 + \nu^2) l^2 + \nu^2 r^2} \} \text{ P}$$
$$= \{ 1{\cdot}513 (\mu + \nu) l + {\cdot}828 \nu r \} \text{ P nearly,}$$

in which form it is easy, after substituting values for l and r, to find the angle at which the stress is greatest. For instance, if we put $l = 20$, $r = 30$, we shall find that the expression in brackets is near its maximum for angles of 67½° in Table I., and 90° in Table II.: the approximate formula gives the greatest equivalent moment = 63 P; recalculating by the exact formula we get the moment = 57 P, or more than five times the mean twisting moment.

Example 2.—*Crank-shaft of a pair of marine engines* of 500 collective nominal H.P. Cylinders 80 inches effective diameter; stroke 42 inches; initial effective load on piston = P = 71·8 tons. (Fig. 2, p. 66).

Supporting forces at crank-shaft journals.—Since the crank-shaft is not only continuous over two spans, but also continuous with the propeller shaft, the supporting forces corresponding to the loads on the crank-pins are modified by the influence of the continuity. Supposing the bearings *exactly* in line, the calculation of the supporting forces, though the problem is definite, is rendered difficult by the irregularity of form of the crank-shaft. On the other hand, the exact line of

the bearings cannot be insured in practice, and from the stiffness of the crank-shaft, a very small defect of accuracy, such a defect as might result from wear of brasses or bending of framing, would considerably affect the distribution of the supporting forces.

Hence, for simplicity, it is assumed in the following investigation that the bending moments may be calculated as if the shaft consisted of two independent spans, and this is not unfavourable to the strength of the shaft. For the continuity which reduces the maximum stresses for two quadrants of the crank's revolution when the steam pressure on both pistons acts in the same direction, augments them in the other quadrants when the loads on the crank-pins act in opposite directions. The most favourable assumption as to the distribution of the pressure on the bearings which it seems reasonable to make is, that the load on each bearing is uniformly distributed.

Let θ be angle which forward crank arms make with their initial position, and θ' the corresponding angle of the aft crank arms. Then the forces acting on the crank-pins are ν P, μ P, ν' P, μ' P, where ν and μ are values in the tables corresponding to θ, and ν' and μ' to θ'. Let $\theta' = \theta - 90$, and for simplicity, put $a = \frac{l_1}{l_1 + l_2}$; $b = \frac{l_2}{l_1 + l_2}$; then the forces acting on the crank-shaft are :—

	Parallel to forward crank arms.	Parallel to aft crank arms.
Forward bearing	$-b\mu$ P	$-b\nu$ P
Forward crank pin	μ P	ν P
Middle bearing	$-a(\mu + \nu')$ P	$-a(\nu + \mu')$ P
Aft crank pin	ν' P	μ' P
Aft bearing	$-b\nu'$ P	$-b\mu'$ P

Graphic representation of stresses on crank-shaft.—For any one given position of the crank-shaft the distribution of the straining action is most easily ascertained by a graphic process.

(1.) *Bending action due to forces parallel to tangential force on forward crank-pin,* Plate III., fig. 1—Suppose first the forces concentrated at the centre of the bearings, and find the supporting forces due to ν P at the forward crank-pin, and μ' P at the aft crank-pin. These will be found to be for $\theta = 135°$ and $\theta' = 45°$,—

$$\nu \text{ P} = 33{\cdot}6 \text{ tons.} \quad \mu' \text{ P} = 33{\cdot}6 \text{ tons.}$$

Supporting forces:—

Forward bearing — 17·9; middle — 32·8; aft — 19·4. Set off these forces to a convenient scale on the vertical $a\ b$, taking them in order and measuring them upwards or downwards according as the forces act in one direction or the other. The line $a\ b$ so divided represents the polygon of external forces, and it necessarily closes at c, supposing we have taken the forces in order from one end of the shaft. Draw $c\ O$ horizontal, and for convenience take $c\ O$ = radius of cranks. Join O with the division points of $a\ b$. Produce $a\ O$ to the vertical through the centre of crank-pin bearing (direction of ν P). Draw $a_1\ a_2$ parallel to $O\ d$; $\bar{a}_2\ a_3$ parallel to $O\ e$; $a_3\ a_4$ parallel to $O\ b$. Then the bending moment of the shaft and crank-pins in the given plane, at any point, is proportional to $c\ O \times$ the vertical ordinate of the figure $a\ a_1\ a_2\ a_3\ a_4$ at that point.

(2.) *Bending action due to forces parallel to radial force on forward crank-pin*, or perpendicular to preceding forces. There are acting

μ P = 43·0 tons on forward crank-pin,
ν' P = 45·9 „ aft „

Corresponding to which the supporting forces are:—

Forward bearing — 22·9; middle — 41·5; aft — 24·5. Setting these off as before at the aft journal to avoid confusion, we get the bending moment area $a_4\ b_3\ a_3\ b_1\ a$.

(3.) *Resultant bending moments.*—Take $A\ l = A\ a_1$, and set off $A\ c_1 = l\ b_1$. Then c_1 is a point in the curve of resultant bending moments. Find c_3 in the same way, and join $a_4\ c_3\ a_2\ c_1\ a$. This is the figure whose ordinates are proportional to the resultant bending moments.

To allow for uniform distribution of loads over surface of bearings.—As the distribution of the pressure is unknown, an exact construction is not required. Drop verticals at the extremities of each bearing on the moment area, and replace the straight boundaries of the moment area, beneath each bearing, by circular arcs tangential to the remaining portions of the moment area. The figure so obtained will be almost exactly the moment area for loads uniformly distributed on the bearings.

(4.) *Twisting moments.*—Since the polar distance $c\ O$ has been taken = the crank radius, which is the lever arm of the forces, producing twisting moments on the shaft and crank-pins, the

twisting moment due to any force P will be given, on the same scale as the bending moments, by P units on the scale of tons.

Looking at the end view of the shaft and considering the forces to the right of any section of the shaft, it is easy to see that there is no twisting action from a to m. From m to n (forward crank-pin) the twisting moment is the supporting force at a due to the tangential force at A (=17·9 tons) $\times$ crank radius. Take $m\ d_1 = n\ d_2 = 17{\cdot}9$ on scale of tons, and join $d_1\ d_2$. From n to o, the twisting action is the tangential force on forward crank (33·6 tons) $\times$ crank radius: take $n\ d_3 = o\ d_4 = 33{\cdot}6$ and join $d_3\ d_4$. On the aft crank-pin the twisting force will be seen to be $33{\cdot}6 - 43 + 22{\cdot}9 + 41{\cdot}5 = 55$ tons. These are all the forces to the right of B whose directions do not pass through the pin. Take $o\ d_5 = p\ d_6 = 55$ and join $d_5\ d_6$. Lastly take $p\ d_7 =$ tangential force on two crank-pins and draw $d_7\ d_8$ horizontal. The area of twisting moments is thus completed.

(5.) *Ideal twisting moment equivalent to bending and twisting moments.*—From any vertical $q\,r\,s$ reflect the twisting moment $q\ s$ to $q\ o$. From r on the bending moment curve set off $r\ t = r\ o$. Then t is a point in the curve of the ideal equivalent twisting moment (T_i).

At any point q, the moment in inch tons is found by multiplying $q\ t$ on the scale of tons by $c\ O$ on the scale of inches. Fig. 2, Plate III., exhibits an exactly similar construction for cranks at 225° and 135° with the initial position.

The graphic process, so convenient and rapid for finding the distribution of stress in the shaft at any given position of the cranks, is inconvenient for seeking the position for which the stress on any part is greatest. It is now, however, easy to write down, algebraically, the moment on any section of the shaft or crank-pins. The complicated general expression so obtained may then be reduced to a simple approximate form by Poncelet's theorems, and it is then easy to seek in the tables the angles for which that expression is greatest.

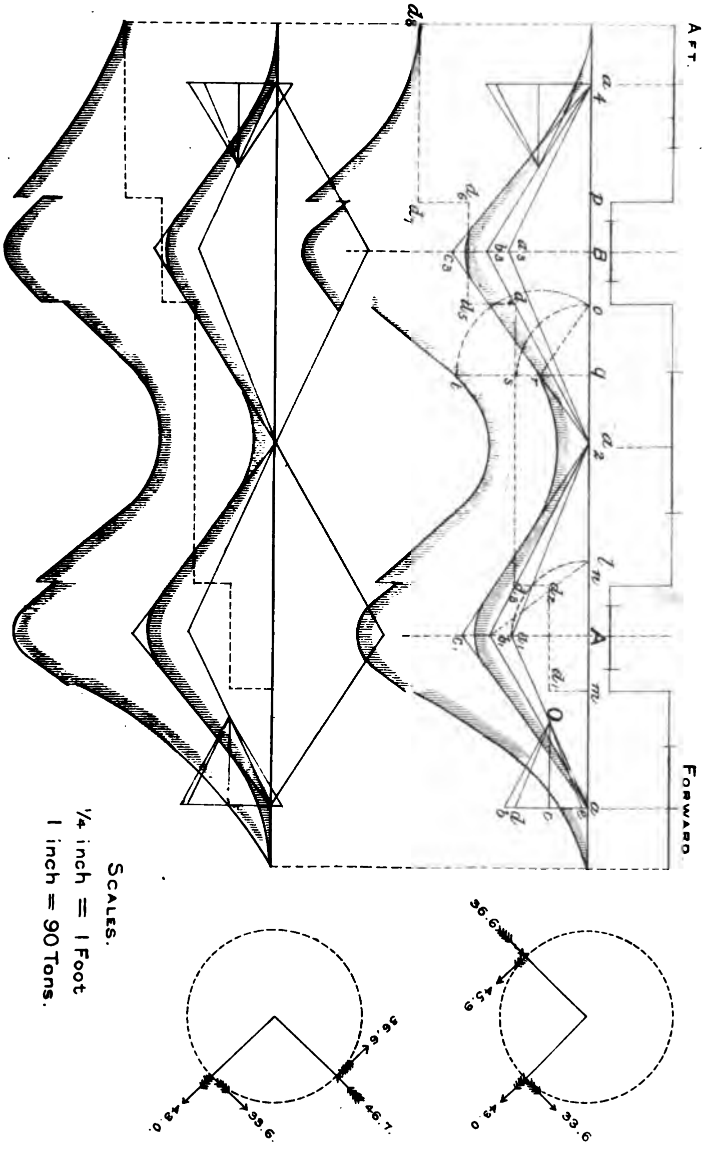
Forward Journal.—This journal is subjected only to bending, most severe at its inner edge, where the moment is,—

$$\begin{aligned} M &= \tfrac{1}{2}\, b\, P\, \lambda_1 \sqrt{\mu^2 + \nu^2} \\ &= {\cdot}414\, b\, P\, \lambda_1 (\mu + \nu) \text{ nearly.} \end{aligned}$$

Plate 3.

GRAPHIC REPRESENTATION OF BENDING AND TWISTING MOMENTS.

FIG. 2. FIG. 1.



UNWIN BROS: LITH

Middle Journal.

$$\text{Bending moment} = \tfrac{1}{2}\, a\, \mathrm{P}\, \lambda_2 \sqrt{\mu^2 + \nu^2}$$

$$\text{Twisting moment} = \nu\, \mathrm{P}\, r$$

$$\begin{aligned} \mathrm{T}_1 &= \mathrm{P}\left\{ \tfrac{1}{2} a \lambda_2 \sqrt{\mu^2 + \nu^2} + \sqrt{\tfrac{1}{4} a^2 \lambda_2^2 (\mu^2 + \nu^2) + \nu^2 r^2} \right\} \\ &= \mathrm{P}\left\{ \cdot 579\, a\, \lambda_2 (\mu + \nu) + \cdot 96\, \nu\, r \right\} \text{ nearly.} \end{aligned}$$

Aft Journal.

$$\text{Bending moment} = \tfrac{1}{2}\, b\, \mathrm{P} \sqrt{\mu'^2 + \nu'^2}\, \lambda_1$$

$$\text{Twisting moment} = (\nu + \nu')\, \mathrm{P}\, r$$

$$\begin{aligned} \mathrm{T}_1 &= \mathrm{P}\left\{ \cdot 5\, b \lambda_1 \sqrt{\mu'^2 + \nu'^2} + \sqrt{\cdot 25\, b^2 \lambda_1^2 (\mu'^2 + \nu'^2) + (\nu + \nu')^2 r^2} \right\} \\ &= \mathrm{P}\left\{ \cdot 579\, b\, \lambda_1 (\mu' + \nu') + \cdot 96 (\nu + \nu') r \right\} \text{ nearly.} \end{aligned}$$

Forward Crank Pin.

$$\text{Bending moment} = \mathrm{P} \sqrt{\mu^2 + \nu^2} \left(b\, l_1 - \frac{\lambda}{8} \right);$$

$$\text{for simplicity} = c\, \mathrm{P} \sqrt{\mu^2 + \nu^2}$$

$$\text{Twisting moment} = b\, \nu\, \mathrm{P}\, r$$

$$\begin{aligned} \mathrm{T}_1 &= \mathrm{P}\left\{ c \sqrt{\mu^2 + \nu^2} + \sqrt{c^2 (\mu^2 + \nu^2) + b^2 \nu^2 r^2} \right\} \\ &= \mathrm{P}\left\{ 1\cdot 514\, c (\mu + \nu) + \cdot 828\, b\, \nu\, r \right\} \text{ nearly.} \end{aligned}$$

Aft Crank Pin.

$$\text{Bending moment} = c\, \mathrm{P} \sqrt{\mu'^2 + \nu'^2}$$

$$\text{Twisting moment} = \mathrm{P}\, r (\nu + a \nu')$$

$$\begin{aligned} \mathrm{T}_1 &= \mathrm{P}\left\{ c \sqrt{\mu'^2 + \nu'^2} + \sqrt{c^2 (\mu'^2 + \nu'^2) + (\nu + a\nu')^2 r^2} \right\} \\ &= \mathrm{P}\left\{ 1\cdot 514\, c (\mu' + \nu') + \cdot 828 (\nu + a \nu') r \right\} \text{ nearly.} \end{aligned}$$

As an example of the manner of using these formulæ, let us substitute the values of a, c, and r given in fig. 2, p. 66; we get for the aft journal

$$\mathrm{T}_1 = (9\cdot 57\, \mu' + 29\cdot 73\, \nu' + 20\cdot 16\, \nu)\, \mathrm{P} \text{ nearly.}$$

Suppose the maximum cut off at $\frac{1}{2}$. Then the expression in brackets can easily be seen to be near its maximum for $\theta' = 67\frac{1}{2}°$ and $247\frac{1}{2}°$ in Table I., and $67\frac{1}{2}°$, $112\frac{1}{2}°$, & $292\frac{1}{2}°$, Table II. The greatest value is found at $247\frac{1}{2}°$, where the approximate formula gives the moment = 34·9 P. Re-calculating by the exact formula for that angle, the moment is 33·5 P., or 1·5 times the mean twisting moment of the pair of engines. For the aft crank-pin, the greatest moment will be found to be 2·1 times the mean twisting moment of the two engines. The moments of the crank-arms may be found in a similar manner.

THE WOODS USED IN SHIPBUILDING:

THEIR CHARACTERISTICS AND SPECIAL APPLICATIONS.

By Samuel Thearle, Fellow of the Royal School of Naval Architecture and Marine Engineering.

In this article it is intended to consider briefly the kinds of trees used in ships at the present time, and to notice their characteristics and the purposes to which they are applied.

All *timber* trees belong to the *exogenous* tribe of plants, which increase in bulk by additions to the external surface. They are divided into two classes—viz., leaf and cone bearing, which may likewise be distinguished as non-resinous and resinous respectively. The latter includes all kinds of firs and pines; the former all other varieties of the above-mentioned tribe.

Of the former class the following trees are those chiefly used in shipbuilding, viz.:—Oak, teak, elm, mahogany, greenheart, sabicu, mora, ash, and lignum-vitæ. Of the latter class red or Dantzic pine, yellow pine, cedar, cowdie, Oregon pine, spruce fir, and larch.

An examination of the longitudinal and cross sections of the trunk of a tree shows two distinct kinds of tubes, or grain, as it is termed, formed by the fibre of the wood. These are a longitudinal or vertical series of tubes, grouped so as to form concentric rings, and a series of tubes radiating from the pith at the heart of the tree. The former are termed *vascular tissue*, and the latter *medullary rays*. Besides these, in the former section a great number of small pores or cells are discovered. These are termed *cellular tissue*. The concentric rings of vascular and cellular tissue are divided into groups by the intersection of the medullary rays, which are in planes about normal to the surfaces of the tissues. We have remarked that the medullary rays radiate from the pith; this

last is a soft substance, composed of cellular tissue, and inclosed in the *medullary sheath.*

Under the bark the wood is young and soft, and is termed *sap wood.* This is rarely used, as, except in a few cases, it is very liable to decay.

Without entering into the interesting subject of the manner in which wood grows—a question which belongs rather to the province of botany than to that of naval architecture—we may simply say that the growth takes place under the bark, and that the oldest wood is therefore nearest the centre of the tree.

The concentric rings already referred to are generally considered to be the growth of a year in a temperate climate; but in the tropics they denote the number of wet and dry seasons during which the timber has been growing.

It is asserted by some that the pith is always nearer the north side than the other sides of the tree as it grows, the reason given being that the sap flows more readily under the direct influence of the sun's rays than when shaded. Generally speaking, trees which have these rings close together yield superior timber to those in which they are wider apart.

LEAF-BEARING TREES.

A careful examination of the sections of leaf-bearing trees will at once suggest two principal divisions of this tribe:—

First. Trees with *distinct* medullary rays.

Second. Trees with *indistinct* medullary rays.

Of the former the chief instances are oak, beech, &c. Of the latter, elm, teak, greenheart, mahogany, ash, &c.

These are again sub-divided into those in which the rings are distinct and those in which they are not:—

First division. Medullary rays distinct.	First sub-division. Rings distinct.	Oak, &c.
	Second sub-division. Rings indistinct.	Beech, &c.
Second division. Medullary rays indistinct.	First sub-division. Rings distinct.	Elm, ash, &c.
	Second sub-division. Rings indistinct.	Mahogany, teak, greenheart, lignum-vitæ, &c.

OAK.

The oak is found in all European countries, but chiefly in Great Britain, Italy, Sicily, Spain, and Prussia. It is also indigenous to North America.

The two chief varieties of oak found in the British Isles are superior for general shipbuilding purposes to all the others. These two varieties are principally distinguished by the manner in which the acorn grows upon them, and are termed the stalk-fruited oak (*Quercus robur*) and the cluster-fruited species, or *Quercus sessiliflora*, respectively. The latter is sometimes known as the Durmast oak, and the former as the true English species.

The stalk-fruited oak is by far the better of the two for shipbuilding purposes, although the Durmast oak is very commonly used.

The Sicilian and Sardinian oaks are valued chiefly for their great curvature, and are therefore very suitable for the frames, especially the floor timbers. As, however, the timber cracks, or "shakes," in drying, it is not suited for other purposes.

Prussian and Polish oaks (known in the market as Dantzic oak) grow very straight and tall, and the timber is tough, and dries without shaking; it is therefore specially adapted for deck plank, to which purpose it is applied. It arrives in this country chopped or sawn into planks of various thicknesses. When the tree is curved, the curvature is cut in the plank, which is bent straight when laid as deck.

A considerable quantity of American oak is now consumed in shipbuilding. The best variety, termed *live* oak, is very hard, and is used for frame timbers, pillars, &c. The American white oak grows to a very large size, and is generally straight. It has sometimes been used for stern-posts on account of its size; but it is neither so strong nor so durable as English oak.

Among the defects to which oak is liable the following are the most common:—*Cup shakes*, caused by the sap freezing under the bark, and separating two of the ring

layers, which remain thus separated throughout the future growth of the tree. *Rind galls*, produced by damaging the inner bark, or by improperly lopping the branches; the wounded part decaying, and the future growth covering it up. Extensive rottenness from this cause is sometimes found in the interior of a piece of timber whose surface is perfectly sound. *Foxy stains* occur in timber grown on marshy soils. These are indications of its being in a state of decay. Oaks from damp or sandy soils are very liable to this defect, and are generally much softer and lighter than those grown in more suitable situations. Mountain oak is by far the hardest and most durable of all.

The introduction of iron for shipbuilding purposes, besides lessening the amount of oak timber required for the frames and side planking, has also precluded its use in places where wood is still required from the fact of its containing gallic acid, which dissolves the iron with which it comes in contact.

The principal application of oak in wooden ships is as frame timbers, plank both of side and deck, stems, sternposts, pillars, topside chocks, and sometimes as beams. In iron ships, for the reason stated, it is rarely used, except as deck plank and towing-chocks.

BEECH.

Beech is very little, if at all, used in the Royal Navy; in merchant ships it is sometimes employed as bottom plank under water. It is very liable to dry rot.

ELM.

This tree is indigenous to, and attains its highest state of perfection in, this country. It is valuable chiefly on account of its lateral toughness, the fibre being intertwined; it is, however, very subject to shrinkage, warping, and alteration of form: besides which it cannot be used with advantage in situations where it is liable to become alternately wet and dry, as under these circumstances it speedily rots. When constantly under water it is very durable, and even seems to be

improved by a lengthened period of immersion in salt water. It is therefore specially adapted and generally used for keels, garboards, and planking of bottom under water. Elm is the chief timber used in boatbuilding, although for the diagonal-built large boats of H.M. Navy mahogany has superseded it.

A kind of timber termed Canada rock-elm is now in very common use. It is a light-coloured, straight, close-grained, and very flexible wood; it grows to a great length, and of nearly uniform dimensions throughout. It is much used for boats, ladders, gratings, planking, and in some cases even for beams.

ASH.

Ash is a wood but little used in shipbuilding. It is a native of Great Britain, and is often found of very large dimensions. It is light-coloured, and very elastic and tough, and is chiefly worked into capstan-bars, handspikes, and other similar appliances.

MAHOGANY.

This timber, which but a few years since was used only by the cabinet-maker, now enters largely into the construction of ships.

It is of two kinds, distinguished as Spanish, or Cuba, and Honduras mahogany. The former is obtained from the West India Islands, and the latter from the countries of Central America. Spanish mahogany is chiefly used for ornamental purposes on account of its greater hardness and its superior appearance. Honduras mahogany has a coarser grain, grows in larger logs, is tougher, and generally far better adapted to structural purposes than the former. Great care is required in its selection, as some kinds, owing to their growing in swampy soils, are very light, spongy, and liable to decay. In fact, the heavier Honduras mahogany is, the better it is found to be. Cuba mahogany may be easily distinguished from Honduras by its having the pores or cellular tissue filled with a chalky substance, those of Honduras mahogany being empty.

Cuba mahogany is used for cabin furniture, steering-

wheels, binnacles, and other work which is made ornamental as well as useful.

Honduras mahogany is usually employed for inner and outer side-plank, beams, waterways, shelves, the plainer portions of cabin furniture, &c.

TEAK.

Teak is now the most useful wood employed in shipbuilding, both from its great strength, toughness, and durability, as well as from its not injuriously affecting iron with which it may be in contact. It is also very free from shakes or shrinkage when drying. The best teak is procured from Malabar, although a great deal of inferior wood is imported from Ceylon, Java, and the Malayan Peninsula.

The chief defects in this timber are worm-holes, which are frequently found to traverse the interior of the log in all directions, the surface appearing sound. Great waste therefore occurs in converting it, and much judgment is required in selecting it for purchase. Good teak when freshly cut is usually of a greenish-brown colour, changing to reddish-brown after a few minutes. It contains a great quantity of an oily substance, and is therefore very inflammable.

At the heart of teak a peculiar deposit is often found which dulls the edge of carpenters' tools when working it. It has a chalky appearance, and at first sight one would be led to suppose that it came there by artificial means; but upon careful inspection it is found that the cellular tissues in the neighbourhood of the heart, or pith, are charged with the substance. Mr. J. Davidson, the teacher of chemistry to the Royal School of Naval Architecture, has analysed some specimens, and found them to consist of phosphate of lime, which had presumably been abstracted from the soil, and secreted at the centre of the tree, similar to camphor and other resins.

Teak is chiefly used for backing behind armour-plates, deck-flats, beams, inner and outer side plank, sometimes for frame timbers, also for bulkheads, companions, skylights, coamings, &c. It is also frequently chosen in preference to mahogany for cabin furniture, as when polished it has an

appearance very like walnut, from which wood knotty specimens of teak can hardly be distinguished. The shrinkage of teak when drying is inconsiderable; hence it is very useful for the engine and boiler bearers of wooden ships and for other such purposes.

GREENHEART.

This wood is obtained from British Guiana, where it attains a great height. It grows very straight, and is very liable to split. Its colour is generally a greenish yellow, but in the most valued varieties it is black. It is highly esteemed for its durability under water, and its freedom from the attacks of marine insects. It is used for waterways, shelves, plank of bottom, &c.

AFRICAN OAK.

This timber is procured from Western Africa. It grows very straight and long, and is somewhat similar in appearance to teak, but heavier, harder, and usually in smaller logs. It is not suited for work under water, as it is very liable to attack from marine insects. The chief application of African oak is for keelsons, pillars, beams, waterways, and frequently for sheerstrakes and wales. It is very liable to destructive shakes at the heart when drying, and to perforation by insects.

SABICU.

This is a very hard kind of timber, somewhat similar to coarse-grained, deep-coloured mahogany in appearance, but considerably harder and heavier. Its grain is very short, and the fibres are usually very much twisted and interlaced. From its great hardness and toughness it is very much used for such parts of a ship as need these qualities, and at the same time do not require longer pieces than can be obtained with tolerably straight grain—for instance, bitts, bollards, cleats, &c. It is a very durable wood, but is frequently found shaken at the heart, while the outside is perfectly sound.

MORA.

This wood has but recently been introduced into shipbuilding, and as yet has not been used to a sufficient extent

to enable us to judge exactly of its qualities. It seems, however, to be durable and tough, and very difficult to split. Its chief application, as yet, has been for side plank. It is procured from British Guiana, where it is found in great abundance.

LIGNUM-VITÆ.

This is procured from the West India Islands, and is a very useful wood, both to the rigger and the marine engineer. It is remarkably tough, dense, and heavy, and has the property of resisting crushing forces with nearly equal strength along and across the grain. Hence, being excessively hard, it is very useful for dead-eyes, sheaves, and rollers. The sap wood is very much lighter in colour than the heart, the latter being a dark green, while the former is nearly yellow. In cutting a log for sheaves the direction of the grain should be parallel to the axis of the sheave, and in making the latter it is usual to leave a ring of sap wood around the heart wood, in order to prevent it from splitting by too rapid drying. The marine engineer uses it for shaft-bearings when in contact with sea-water.

CONE-BEARING TREES.

The coniferous trees are divided into two classes—pines and firs. The former have needle-like leaves, growing in clusters from the same stalk; the latter have them straight and separate, but many growing on the same leaf-stalk, like the teeth of a comb. In shipbuilding the pines are far more useful than the firs, for besides attaining a larger size, they are generally more durable and stronger. All the coniferous trees are characterised by a straightness of growth, which, combined with their lightness and flexibility, render them specially suitable for masts and spars. They have, however, many other important applications, as will be seen presently.

RED OR RIGA AND DANTZIC PINE.

The most useful of all the pines used in shipbuilding is the *Pinus silvestris*, commonly known either as Red, Dantzic, or Riga Pine. That obtained from Riga is the best on account of its size, strength, and flexibility, making it suitable

for the larger spars of ships, such as the lower masts and topmasts. It is a reddish-coloured wood, the depth of tint varying with the amount of resin contained.

It is also very much used for the deck plank of ships, the outer cuts, free of heart, being termed Dantzic Crown Deals; those at the heart are inferior, and sold at a lower price.

YELLOW PINE.

This is the largest kind of pine now commonly obtained, and is imported from Canada. It is very much used for large masts and yards, for neither of which purposes, however, is it so well adapted as Riga pine, being considerably lighter, and not so elastic, strong, or durable. Large spars of the latter wood are, however, getting very scarce, and hence yellow pine is superseding it.

The decks of passenger ships and yachts are sometimes made of this wood on account of its light colour and freedom from knots. It is very much used for cabin bulkheads and other light fittings. It is now grown in Great Britain, being known as the Weymouth Pine.

OREGON PINE.

A species of red pine, obtained from Oregon and the adjacent island of Vancouver's, is now becoming very generally used for lower and topmasts, and as it grows to a large size, at the same time being very straight, tough, flexible, and durable, it is a very good substitute for Riga pine, which, as has been already remarked, is now rarely obtained of large proportions. Spars of this pine 130 feet in length have been brought to this country, and one of gigantic dimensions was presented to the Queen about four years since by the Colonial Government. The mast, when planed, shows a pretty waved grain, which is much esteemed by seamen. The trees brought from the mainland are superior to those from the island, being generally freer from knots. The chief disadvantage its use has at present is its high price, due chiefly to the heavy charges for freightage.

COWDIE PINE.

This is a species of pine recently imported in large

quantities from New Zealand. It grows to a very great size, and has been used for some of the largest spars in a ship. It, however, lacks elasticity, and is very liable to warping and shaking. Being very free from knots it is sometimes used for the decks of pleasure vessels, as, when planed or cleaned, it has a most agreeable light yellow colour.

SPRUCE FIR.

The chief variety of the fir tribe as regards its use in shipbuilding is the spruce, *Pinus abies*, which grows in Norway, Scotland, and other northern countries. It is used for the small spars of ships and for boats' masts. The wood is tough, close-grained, and elastic, and also whiter than the pines. As it is very full of large knots, great care is required in the selection. Spruce deals are used for some of the lighter fittings of ships, but not generally to the same extent as yellow pine.

LARCH.

The larch is common to Northern Europe, although it has been grown in this country only during the past century. The Duke of Athole was the first to plant it in Scotland on his estate at Blair Athole, about the year 1738, since which time it has become very common.

It is a timber of great strength, and remarkable for its durability when exposed to the weather, but it is much harder to work and more liable to warp than Riga pine.

The larch has not yet been extensively used in shipbuilding.

CEDAR.

This is a species of fir more frequently used for ornamental than for useful work, as it is very weak. It is, however, almost indestructible from time, and no insect will attack it. It is chiefly used for cabin furniture, and in such parts of the ship's hull where durability and no great strength may be required.

ROYAL SCHOOL OF NAVAL ARCHITECTURE AND MARINE ENGINEERING,

SOUTH KENSINGTON.

OFFICERS OF THE SCHOOL.

Inspector-General	REV. JOSEPH WOOLLEY, LL.D., F.R.A.S.
Principal	CHARLES W. MERRIFIELD, F.R.S.
Vice-Principal	JAMES H. COTTERILL, M.A.
Instructor in Marine Engineering	W. CAWTHORNE UNWIN, B.SC.
Instructor in Naval Architecture	WILLIAM H. WHITE, F.R.S.N.A.
Instructor in Ship Drawing .	WILLIAM B. BASKCOMB, M.I.N.A.
Instructor in Marine Engine Drawing	JOHN MAXTON.
Instructor in Practical Chemistry	JOHN DAVIDSON.
Instructor in French . . .	JULES PENON.

The Lords of the Committee of Council on Education, after communication with the Admiralty and the Institution of Naval Architects, opened at the South Kensington Museum, in the year 1864, a School of Naval Architecture and Marine Engineering.

This school is for the instruction not only of Admiralty pupils from the Royal Dockyards, and Officers of the Royal Navy, but also of Naval Architects, and Ship Builders in wood and iron, Marine Engineers, Foremen of Works, Shipwrights, and other persons desirous of studying Naval Architecture or Marine Engineering.

The course of instruction is calculated to last for four sessions, on the supposition that the student enters the School with a fair knowledge of Drawing and Practical Geometry, and an elementary knowledge of Mathematics and Physics.

The instruction embraces the subjects specified for the final examinations. While there is room, students may be admitted to the Special Classes on Professional Subjects, without attending the general course.

The Session of the School commences on the 1st of October, and lasts till the 30th of the following April. The students are expected to pass the summer five months in practical work, either in a Dockyard or in a Marine Engine Factory, public or private.

Admission.

The fee (payable in advance) for the full course of instruction is £25 for each session of seven months, or £80 for the course of four sessions.

Students who have already paid one fee of £25 are allowed to compound for the next three sessions by a payment of £60 at the commencement of the second session.

Students who have already paid the fees for two sessions are allowed to compound for the two remaining sessions by a payment of £42 at the commencement of the third session.

Students allowed to join the School after Christmas are charged £5 for each remaining month of that session unless they prefer to compound.

Proportionate fees are charged to students attending Special Classes only.

Officers in Her Majesty's Service are admitted to the full course on payment of £10 per session.

Persons desiring admission must apply by letter to the "Secretary, Science and Art Department, South Kensington, London, W."

Lectures.

Courses of Practical and Experimental Lectures (see Lecture List appended, p. 91), which may be attended separately, are given on such of the subjects of instruction as admit of, or require, illustration by this means.

The public is admitted to these Lectures on payment of a fee of £2 for the full course; or to each separate Lecture on payment of 1s. Officers in Her Majesty's Service not attending the School are admitted on payment of a fee of £1.

School Scholarships and Free Studentships.

Four Free Studentships, to two of which are attached Scholarships of £50 per annum, tenable for four sessions, are given in competition at the commencement of each session if qualified candidates present themselves. They are only open to students on entering; but if not all filled up in any one year, students who have studied for one or two sessions at the School can compete for as many as be vacant, should the examination passed by them at the end of the previous session have been very satisfactory.

No person is permitted to compete who has not already been admitted as a student, and paid the fee, which will be returned to him in the event of success.

The subjects of the Competitive Examination, with the number of marks assigned to each, are as follows :—

1. Pure Mathematics, including Arithmetic, Plane and Descriptive Geometry, Plane Trigonometry, and the Elements of the Differential and Integral Calculus	2,500
2. Theoretical and Practical Mechanics, or Applied Mathematics	1,500
3. Practical Shipbuilding	2,000
4. Marine Engine and Engineering	2,000
5. Physics	500
6. Chemistry	500
7. Mechanical and Professional Drawing	500

This examination is not open to Admiralty students, nor to any but British subjects.

Admiralty Scholarships.

The Lords Commissioners of the Admiralty have made the following arrangements for a Competitive Examination for the admission of persons not already in the Government Service to the School as Admiralty students:—

Candidates are examined either as Naval Architects or as Marine Engineers; they must not be less than 18 or more than 21 years of age, and must have served at least two years in a Dockyard or in an Engineering Establishment, or must give satisfactory proof of having in some way been so connected with Shipbuilding or Engineering operations as to become well grounded in the elementary principles and practice thereof.

Those candidates who may be selected will be treated while attached to the School in all respects as the Admiralty students, and will receive wages, commencing at 1s. 6d. per day, for six days per week for first year, increasing yearly 3d. per day till they reach 2s. per day; and, in addition, a subsistence allowance of 3s. per day, for seven days per week, while they are away from their homes, either at the School or in the Royal Dockyards.

It is to be understood that the Admiralty makes no engagement to employ these students after the completion of their course of study; they must rely on their own worth as educated Naval Architects or Marine Engineers for obtaining employment in their subsequent career.

The subjects of the Competitive Examination, with the number of marks assigned to each, are as follows:—

1. Pure Mathematics, including Arithmetic, Mensuration, Plane and Descriptive Geometry, Plane Trigonometry, and the Elements of the Differential and Integral Calculus	2,500
2. Applied Mathematics, including Mechanics and Hydrostatics	1,000

3. Practical Shipbuilding, including Laying Off (for Naval Architect Candidates only)	2,500
4. Practical Marine Engineering (for Marine Engineer Candidates only)	2,500
5. French...	500
6. Elements of Physics and Chemistry	750
7. English Grammar and Composition	750
8. Geography and History	750

No Candidate will be admitted to the School who does not obtain at least two-thirds of the full number of marks in the first and second subjects, and three-fifths of the full number either for Practical Shipbuilding or Marine Engineering.

The last four subjects, although counting in the competition, will not be considered obligatory.

This Examination is only open to British subjects.

The time and place of examination, the number of students to be selected, and full particulars, are advertised in the *Times* in June every year.

Collateral Advantages.

Permission to devote the five summer months to actual work and the acquirement of practical knowledge in the Royal Dockyards is granted by the Admiralty to all Private Students of the School being British subjects.

Arrangements are occasionally made for the students to visit Public and Private Works, by the courtesy of the owners and authorities of the establishments.

Hours of Study.

The usual hours of study are from 9 to 12, from 2 to 5, and from 7 to 9 on Mondays, Tuesdays, Thursdays, and Fridays, and from 9 to 12 only on Wednesdays and Saturdays. The Public Lectures take place from 5 to 6 p.m. on two or three evenings weekly.

Inspection.

All the students are examined at the end of each session: at the end of his fourth session each student is examined for the Diploma of Associate or Fellow of the School.

Examination for Diplomas.

Diplomas are granted to all persons, whether they have received their instruction at the School or not, who pass the final examinations, provided they give satisfactory evidence of having gone through the course of practical work recommended by the Council of the Institution of Naval Architects.

These Diplomas are of two grades according to the success of the candidate in the examination, the title of the higher grade being Fellow, and of the lower Associate of the Royal School of Naval Architecture and Marine Engineering. This examination is held annually towards the end of April.

In case of failure at the Examination the student may either remain at the School for another session at a fee of £25, or he may present himself at any future examination whenever he considers himself qualified.

Candidates who have not been students of the School are required to produce certificates that they have been engaged for three years at least in—

1. Practical wood or iron shipbuilding in a Dockyard; or,
2. Practical engine and boiler building in a Dockyard, or in a Marine Engine Factory; or,
3. Practical work as a Draughtsman in a Dockyard or in a Marine Engine Factory, during which the candidate himself must have gone through the complete formation of the design of a ship, or of a marine engine, with the whole of the designs included in it.

Such candidates are also required to give references as to character and good conduct before being admitted to the examination.

All such candidates must apply to the "Secretary, Science and Art Department, South Kensington, W.," not later than the 15th March in each year.

Candidates are examined either as Naval Architects or as Marine Engineers.

* Subjects and Marks for the Diploma of Associate. (Examination of 1872.)

Group A.

Naval Architects.	No.	*Marine Engineers.*	No.
Practical shipbuilding	1,000	Practical engineering	1,500
Laying off	1,000	Proportions and arrangement of marine engines, boilers, and propellers	1,500
Usual calculations of a ship	1,000		
† Elementary physics	1,000	Elementary physics	1,000
Strength of materials	500	Strength of materials	500
Heat and steam	500	Heat and steam	500

Note.—Half the possible marks to be obtained in each of the three groups as a condition of the Associate's diploma. The schedule will be revised from time to time as occasion may require.

* The examination for April, 1871, will be conducted as heretofore. Candidates desirous of being examined then should apply without delay to the Secretary of the Science and Art Department for detailed information.

† An elementary knowledge of chemistry, electricity, and magnetism, with especial reference to the errors of compasses of ships, both of wood and iron.

Group B.

Naval Architects and Marine Engineers.

	No.
Arithmetic and mensuration	1,000
Algebra, including quadratic equations; and Euclid, first six books and 22 propositions of Book XI., with deductions	1,000
*Plane trigonometry and logarithmic calculation	1,000
†Elementary mechanics and hydrostatics	1,000
	4,000

Group C.

Naval Architects.	No.	*Marine Engineers.*	No.
‡Ship drawing	1,000	‡Engine drawing	1,000
Total marks possible	10,000	Total marks possible	10,000

Subjects and Marks for the Diploma of Fellow (1872).

Group A.

Naval Architects.		*Marine Engineers.*	
Design of a ship	500	Design of a pair of marine engines with boilers and propeller	500
Principles of design of a ship	500	§Principles of design of marine engines boilers and propellers	750
Practical shipbuilding and laying off	1,000	‖Practical engineering	750
‖The steam-engine	500	Practical shipbuilding	500
Heat and steam	500	Heat and steam	500
Strength of materials and structures	750	Strength of materials and structures	750
¶Physics	500	¶Physics	500
**Chemistry and properties of metals	750	**Chemistry and properties of metals	750
	5,000		5,000

Note.—At least 2,500 marks must be obtained in each of the two groups A and B as a condition of the Fellow's diploma. In case of failure, the examiner will judge whether the knowledge shown by the candidate is sufficient to admit of his being received as an *Associate.*

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* Plane trigonometry, as usually read, exclusive of trigonometrical analysis.

† Including (*inter alia*) the description and explanation of the principal mechanical and hydrostatical instruments and machines, specific gravity, and the flotation of bodies.

‡ The ship and engine drawing will be done by the candidate at home "on honour." Instructions will be sent to any candidate applying in proper time.

§ Including a knowledge of the arrangement and proportions of simple and compound marine engines and their appendages; of the mode of representing slide valve motions, and of the use of the indicator; and of the rules for calculating the power of engines and performance of vessels, and the efficiency, evaporation, consumption of fuel, and strength of boilers.

‖ Including a knowledge of the processes of an engineering factory, of the construction and mode of operation of engines and machinery generally, and of the working of engines on ship-board.

¶ Including the elements of pneumatics, electricity, and magnetism, with its application to ships, both of wood and iron.

** A fair knowledge of inorganic chemistry and qualitative analysis.

Group B.

Naval Architects.	No.	*Marine Engineers.*	No.
*Pure mathematics	1,500	*Pure mathematics	1,500
†Applied mathematics	2,000	†Applied mathematics	2,000
Propulsion and resistance of ships and theory of waves	750	Propulsion and resistance of ships and theory of waves	750
Stability and oscillations of ships	750	‡Mechanical theory of heat	750
	5,000		5,000
Total marks possible	10,000		10,000

Books.

The following is a list of the books at present used in the School:—

	Publishers.
Aldis's Solid Geometry	Deighton, Bell, & Co.
Besant's Elementary Hydrostatics	,,
,, Hydrostatics and Hydrodynamics	,,
Boole's Differential Equations	Macmillan.
,, Finite Differences	,,
Drew's Geometrical Conic Sections	,,
Golding Bird and Brook's Natural Philosophy	Churchill.
Goodeve's Elements of Mechanism	Longman.
Logarithms of Useful Knowledge Society	Walton & Maberly.
Main and Brown's Steam Engine	Longman.
,, Indicator and Dynamometer	,,
Parkinson's Elementary Mechanics	Macmillan.
Rankine's Applied Mechanics	Charles Griffin.
,, Steam Engine	,,
Reed's Shipbuilding in Iron and Steel	Murray.
Roscoe's Chemistry	Macmillan.

* The pure mathematics will involve a fair knowledge of the calculus, including (*inter alia*) the elementary parts of calculus of finite differences, and of the calculus of variations, and of differential equations, of analytical geometry of three dimensions, and of descriptive geometry, a thorough acquaintance with the principles of the mensuration of shipbuilding [or marine engineering].

† The applied mathematics will include such subjects as are chiefly useful to naval architects and marine engineers, such as statics, dynamics, hydrostatics, hydrodynamics, theory of internal stress and of elasticity, with the applications of these subjects to the strength of materials and structures, and to machinery.

‡ In its application to the theory of the steam-engine.

BOOKS—*continued.*

Routh's Rigid Dynamics	Macmillan.
Shipbuilding, Theoretical and Practical, by Watts, Rankine, and others	Mackenzie.
Tait and Steele's Dynamics of a Particle	Macmillan.
Todhunter's Algebra	,,
Todhunter's Analytical Statics	,,
,, Conic Sections	,,
,, Differential Calculus	,,
,, Euclid	,,
,, Integral Calculus	,,
,, Plane Trigonometry	,,
,, Spherical Trigonometry	,,
,, Theory of Equations	,,
Twisden's Practical Mechanics	Longman.
Woolley's Descriptive Geometry	,,

LECTURES.

Courses of Public Lectures given in connection with the School from 5 to 6 o'clock in the evening on the days stated below. (Session of 1870-71.) :—

Subjects.	Lecturer.	Dates.
1. Practical Shipbuilding, 9 Lectures	N. Barnaby, Esq., President of the Council of Construction of the Royal Navy	6th, 13th, 20th, 27th January; 3rd, 10th, 17th, 24th February; and 3rd March, 1871.
2. Marine Engineering, 9 Lectures	E. R. Allfrey, Esq.	2nd, 9th, 16th, 30th December, 1870; 3rd, 10th, 17th, 24th, 31st January, 1871.
3. Electricity & Magnetism, 8 Lectures	W. F. Barrett, Esq.	14th, 21st, 28th October; 4th, 11th, 18th, 25th, 28th November, 1870.
4. Metallurgy, 6 Lectures	John Percy, Esq., M.D., F.R.S.	15th, 22nd, 29th November; 6th, 13th, 20th December, 1870.
5. Machinery, 6 Lectures	R. Mallett, Esq., F.R.S.	7th, 14th, 21st, 28th February; 7th, 14th March, 1871.

LIST OF FORMER STUDENTS OF THE SCHOOL.

NAVAL ARCHITECTS.

Name.	A — Admiralty Student. P — Private Student.	Date of Entry.	Date of Departure.	Diploma. A—Associate. F—Fellow.*	Where from.	Present Employment.	Position held.
[1] Blom, H. A.	P	1866	1867	—	Christiania	Norwegian Royal Navy	Lieutenant.
Bone, William James	A	1864	1867	F_2	H.M.D., Dvnpt.	Office of Lloyds' Surveyors, North Shields	Surveyor.
Brown, Alexander McDonald	P	1865	1868	—	Rotterdam	H.M. Dockyard, Chatham	
Deadman, Henry Edward ..	A	1864	1867	F_2	H.M.D., Chtham.	H.M. Dockyard, Devonport	Foreman of the Dockyard.
Elgar, Francis	A	1864	1867	F_1	H.M.D., Ptsmth.	H.M. Dockyard, Portsmouth	Foreman of the Dockyard.
Ewens, Paul...	P	1864	1865	—	London	Laird Bros., shipbuilders, Birkenhead	
[2] Fareed, Hassan	P	Dec. 1868	1869	—	Alexandria		
Fitze, William James ...	A	1864	1867	—	H.M.D., Dvnpt.	J. and W. Dudgeon, Cubitt Town, E.	Assistant Overseer for Admiralty.
Gandy, Charles	P	Dec. 1865	1868	—	London		*Left the profession.*
Gowings, William	A	1864	1867	F	H.M.D., Dvnpt.	Thames Iron Works, Blackwall, E.	Assistant Overseer for Admiralty.
Hansen, George Edward ...	P	1867	1868	—	Cowes, I. of W.	C. Hansen, shipbuilder, Cowes	
[2] Hishmat, Mohammed ...	P	Dec. 1868	1869	—	Alexandria		
John, William	A	1864	1867	F_1	H.M.D., Pmbrk.	The Admiralty, Whitehall, S.W.	Draughtsman.
[3] Leontieff, John	P	1865	1868	—	St. Petersburg	Russian Imperial Navy, St. Petersburg	Lieutenant of Naval Architects.
McAndrew, George	P	1869	1870	—	Low Walker on Tyne		
McCarthy, Michael	A	1866	1870	A	H.M.D., Dvnpt.	Mitchell and Co., shipbuilders, Newcastle	Assistant Overseer for Admiralty.
Made, van der, Dirk Johannes Paulus ...	P	1867	1870	—	Dordrecht		

* The suffixes 1 and 2 denote whether first or second class; without a suffix, third class.

[1] Sent by the Norwegian Government.

[2] Sent by the Egyptian Government.

[3] Sent by the Russian Government.

MARGETSON, Stewart	P	1864	1865	—	London	Thames Iron Works, Blackwall, E	
MARTIN, Oliver James ...	A	1867	1869	—	H.M.D., Ptsmth.		
RAGGE, George Vincent ...	A	1864	—	—	H.M.D., Ptsmth.		*Died in Dec.*, 1866.
RICHARDS, William	A	1865	1868	F_2	H.M.D., Pmbrk.	The Admiralty, Whitehall, S.W. (temporarily.)	Draughtsman.
ROWSE, Joseph William ...	A	1865	1868	A	H.M.D., Ptsmth.	H.M. Dockyard, Portsmouth	Draughtsman.
[1] SOBOLEFF, Victor...	P	1865	1868	—	St. Petersburg	Russian Imperial Naval Reserve, Sebastopol	Lieutenant of Naval Architects.
STANBURY, George	A	1865	1868	F_2	H.M.D., Dvnpt.	The Admiralty, Whitehall, S.W. (temporarily.)	Draughtsman.
STRICKLAND, Thompson ...	P	1865	1869	—	Bristol		
THEARLE, Samuel James Pope	A	1865	1869	F	H.M.D., Dvnpt.	John Elder and Co., Govan, Glasgow	Assistant Overseer for Admiralty.
TREWENT, Francis James ...	P	1866	1869	—	Pembroke Dock.	R. Napier and Sons, ship-builders, &c., Glasgow	
TRIVESS, Thos. Joseph Geary	A	1867	—	—	H.M.D., Ptsmth.		*Died in March*, 1869.
TRUSCOTT, Henry James ...	A	1866	1870	F	H.M.D., Shrnss.	R. Napier and Sons, ship-builders, &c., Glasgow	Assistant Overseer for Admiralty.
[2] TURNBULL, Thomas	P	1864	1867	—	Whitby	Whitehall Dockyard, Whitby.	
[2] VIZETELLY, Adrian	P	1864	1868	A	London	Institution of Naval Architects	
WAMPEN, John Frederic ...	P	1865	1868	—	London	Smith, Pender, and Co., Engineers, Millwall, E.	Draughtsman.
WANHILL, James Manlaws...	P	1865	1865	—	Poole	New Zealand	
WATTS, Phillips	A	1866	1870	F_2	H.M.D., Ptsmth.	Palmer Bros., Jarrow-on-Tyne	Assistant Overseer for Admiralty.
WHITE, William Henry ...	A	1864	1867	F_1	H.M.D., Dvnpt.	The Admiralty, Whitehall, S.W.	Draughtsman.

MARINE ENGINEERS.

BEDBROOK, James Albert ...	A	1864	1867	F	H.M.S.F., Ptsmth.	H.M.S.F., Keyham	Assistant Inspector of Machinery.
BENNETT, Alfred Mosley ...	P	1865	1865	—	Liverpool		
CANTER, William James ...	A	1864	1867	A	H.M.S.F., Keyham	H.M.S. *Zealous*	Engineer.
COW, Douglas	P	1867	1868	—	London		*Left the profession.*
DURSTON, Albert John ...	A	1865	1868	F	H.M.S.F., Ptsmth.	H.M.S. *Ocean*	Assistant Engineer.

[1] Sent by the Russian Government. [2] Held a Free Studentship.

MARINE ENGINEERS—(*continued*).

Name.	A—Admiralty Student. P—Private Student.	Date of Entry.	Date of Departure.	Diploma. A—Associate. F—Fellow.*	Where from.	Present Employment.	Position held.
[1] FARLEY, Ephraim Charles ...	P	1865	1869	A	Truro	Cox, Farley, and Co., engineers, Falmouth	Partner.
GARVEY, John Miller	P	1866	1869	—	London	Henley's Telegraph Works, North Woolwich, E.	Draughtsman.
GRAINGER, James Nixon ...	A	1864	1867	F	H.M.S.F., Ptsmth.	Public Works Deprtmt., Madras	Civil Engineer.
HARDING, William John ...	A	1865	1868	—	H.M.S.F., Ptsmth.	H.M.S. *Inconstant*	Assistant Engineer.
HUMMEL, Alphons Alex. Albert Wilhelm Marie	P	1868	1869	—	Bradford-on-Avon	Bourton Foundry, Dorsetshire	Draughtsman.
[2] IVANHOFF, Nicholas	P	1865	1868	A	St. Petersburg	Russian Imperial Navy, London	Lieutenant of Marine Engineers.
LITTLEJOHN, William George	A	1864	1867	A	H.M.S.F., Keyham	H.M.S. *Philomel*	Engineer.
MARES, William Henry ...	A	1868	—	—	H.M.S.F., Ptsmth.		*Died in July*, 1869.
PRATTEN, William John ...	A	1864	1867	F	H.M.S.F., Wlwich.	H.M.S. *Bristol*	Engineer.
PRICE, George Arthur... ...	P	1867	1868	—	Wolverhampton	Price and Co., Cleveland Safe Works, Wolverhampton	Partner.
[3] SENNET, T. Richard	A	1866	1870	F_1	H.M.S.F., Keyham	H.M.S. *Crocodile*	Assistant Engineer.
SMITH, David Edward... ...	A	1866	1870	A	H.M.S.F., Ptsmth.	H.M.S. Euphrates.	Assistant Engineer.
SMITH, Joseph Andrew ...	A	1865	1868	A	H.M.S.F., Ptsmth.	H.M.S. *Sparrowhawk*	Assistant Engineer.
[2] SOCOLOFF, Vladimir	P	1865	1868	—	St. Petersburg	R.I.S. *Haydamack*	Lieutenant of Marine Engineers.
SOPER, Henry John	A	1865	1868	F	H.M.S.F., Keyham		*Left the profession.*
SPENCE, James Carmichael...	A	1864	1867	—	H.M.S.F., Ptsmth.	R. and W. Hawthorn, engineers, Newcastle-on-Tyne.	Draughtsman.
WARREN, James John... ...	A	1864	1867	A	H.M.S.F., Keyham	H.M.S. *Trafalgar*	Instructor of Marine Engineering to Naval Cadets.
WHELAN, Frederick Astley...	P	1869	1870	—	Dublin	Royal Naval College, H.M.D. Portsmouth.	Lieut. Royal Marine Artillery.
WHITE, William Henry ...	A	1864	1867	A	H.M.S.F., Wlwich.	H.M.S. *Malabar*	Engineer.
YEO, John	A	1866	1870	F_2	H.M.S.F., Keyham	H.M.S. *Serapis*	Assistant Engineer.

* The suffixes 1 and 2 denote whether first or second class; without a suffix, third class.

[1] Held a Free Studentship. [2] Sent by the Russian Government. [3] Obtained a Whitworth Scholarship in 1869.

LIST OF PRESENT STUDENTS OF THE SCHOOL.

NAVAL ARCHITECTS.			MARINE ENGINEERS.		
Name.	A, Admiralty Student. P, Private Student.	Where from.	Name.	A, Admiralty Student. P, Private Student.	Where from.
		Entered in 1867.			
*CEARNS, John Frederick	P	London.	BARRETT, Richard Henry	A	H.M.S.F. Portsmouth.
COTSELL, James	A	H.M.D. Portsmouth.	BURT, Henry	A	H.M.S.F. Keyham.
EDWARDS, Thomas	A	H.M.D. Pembroke.	HEARSON, Thomas Alfred	A	H.M.S.F. Keyham.
PERRETT, Josiah Richard	A	H.M.D. Devonport.	MAYSTON, John Young	A	H.M.S.F. Portsmouth.
*‡ PURVIS, Frank Prior	P	London.	MORCOM, Alfred	A	H.M.S.F. Keyham.
		Entered in 1868.			
BAILEY, Charles Pink	A	H.M.D. Portsmouth.	[2] ANIS, Mohamed	P	Cairo.
BLACK, John	A	H.M.D. Devonport.	[2] ARIF, Mahommed	P	Cairo.
GRIERSON, Frank Willisford	P	London.	BUTLER, Richard Jago	A	H.M.S.F. Keyham.
PHILLIPS, Thomas	A	H.M.D. Pembroke.	CHILCOTT, William Winsland	A	H.M.S.F. Woolwich.
STANLAKE, John	A	H.M.D. Devonport.	CORNER, John Thomas	A	H.M.S.F. Sheerness.
TURPIN, William Woodley	A	H.M.D. Portsmouth.	[2] NAGY, Husseyn	P	Cairo.
			SEATON, Albert Edward	A	H.M.S.F. Keyham.
		Entered in 1869.			
DAVIES, Lewis George	A	H.M.D. Sheerness.	GREEN, William	A	H.M.S.F. Portsmouth.
JAMES, William	A	H.M.D. Pembroke.	MAYSTON, Robert	A	H.M.S.F. Portsmouth.
SMITH, Alfred Weymouth	A	H.M.D. Portsmouth.	WAGHORN, John Waghorn Webb	A	H.M.S.F. Keyham.
SMITH, William Edward	A	H.M.D. Portsmouth.	*WATTS, Luther	P	Portsmouth.
		Entered in 1870.			
ALLINGTON, James	A	H.M.D. Devonport.	BAKER, George Henry	A	H.M.S.F. Keyham.
[1] ARTSAYOOLOFF, Constantine	P	St. Petersburg.	MCADAM, John Alfred	P	Hereford.
CHAMPNESS, Henry Robert	A	H.M.D. Chatham	MILTON, James Tayler	A	H.M.S.F. Portsmouth.
[1] GOULAEFF, Ernest	P	St. Petersburg.	ROBINS, Samuel John	A	H.M.S.F. Keyham.
MCDONALD, John Norman	A	H.M.D. Sheerness	RUDD, Charles	A	H.M.S.F. Portsmouth.
			WALKE, Andrew James	A	H.M.S.F. Keyham.

* Holds the School Scholarship of £50 per annum. ‡ Obtained a Whitworth Scholarship in 1869.
[1] Sent by the Russian Government. [2] Sent by the Egyptian Government.

Gentlemen whose names appear in the preceding tables are requested to notify any change of position, &c., during the ensuing year to the Editor, for alteration in the next number of the Annual.

NON-STUDENT WHO HAS RECEIVED THE DIPLOMA OF ASSOCIATE OF THE SCHOOL.

Name.	Date of Diploma.	Present Employment.	Position held.
WATKINS, Alfred, marine engineer.	1870	Elastic Metallic Packing Works, Bow, E.	Partner.

The particulars in the following Tables have no official authority whatever; they have been either collected from various published sources, or calculated expressly for this Annual. It is requested that corrections and additions may be sent to the EDITOR, Royal School of Naval Architecture and Marine Engineering, South Kensington, W., for alteration in the next number of the Annual.

EXPLANATIONS AND NOTES.

The letter D placed after the name of a vessel signifies that the particulars relating to that vessel are according to either the design or the estimate, the vessel being in process of construction or not having undergone a trial.

The figures given in the column "Thickest Backing," for the WOOD ARMOURCLADS represent the thickness of the sides.

All the Iron Cruisers are sheathed with wood.

The *Hotspur* is the only vessel in H.M. Navy possessing a *fixed* turret.

The *Waterwitch* has a rudder at each end.

The *Sultan* has an auxiliary rudder in each counter.

The particulars of the *Captain* and *Great Eastern* are given as being of general interest.

TABLE GIVING PARTICULARS OF ALL THE IR[ON ...]

Reference Numbers.	NAME.	B.—Broadside. C.—Central Battery. R.—Ram Bow. T.—Turret.	Tonnage.	Weight of Hull.	Dimensions. Length between the Perpendiculars.	Dimensions. Breadth extreme.	Dimensions. Depth in Hold.	Thickness of Armour on. Sides.	Thickness of Armour on. Breastwork.	Thickness of Armour on. Turrets.	Thickest Backing.	Tons of Armour used.	No. of Turrets.	Rudder. O.R.—Ordinary. S.B.R.—Single balanced. D.B.R.—Double.
	Royal Navy. *Iron Armourclads.*			Tons.	ft. in.	ft. in.	ft. in.	in.	in.	in.	ft. in.			
1	Achilles	B.	6121	...	380 0	58 3½	21 1	4½	...	...	1 6	1200		O. R.
2	Agincourt	B.R.	6638	...	400 0	59 5	21 1	5½	...	...	0 10	1776		O. R.
3	Audacious	C.R.	3774	2675	280 0	54 0	24 1	6 to 8	...	...	0 10	924		S. B. R.
4	Bellerophon ...	C.R.	4270	...	300 0	56 1	17 3½	6	...	...	0 10	1089		S. B. R.
5	Black Prince ...	B.	6109	...	380 0	58 0	...	4½	...	...	1 6	975		O. R.
6	Captain	T.	4272	3465	320 0	53 3	...	7	...	...	1 0	1047	2	...
7	Cyclops, D.	T.	2107	...	225 0	45 0	16 6½	...	...	...	...	...		...
8	Defence...	B.R.	3720	...	280 0	54 2	...	4½	...	...	1 6	607		O. R.
9	Devastation, D....	R.T.	4407	3245	285 0	62 3	18 0	10 to 12	10 to 12	12 to 14	1 6	2224	2	O. R.
10	Fury, D.	T.	5030	...	320 0	62 3	...	...	...	...	...	...	2	...
11	Glatton, D.	R.T.	2709	...	245 0	54 0	19 4	8 to 12	12	12 to 14	1 6	2224	1	S. B. R.
12	Gorgon, D.	T.	2107	...	225 0	45 0	16 6½	...	...	...	...	...		...
13	Hecate, D.	T.	2107	...	225 0	45 0	16 6½	...	...	...	...	...		...
14	Hector	B.R.	4089	...	280 2	56 5	...	4½	...	...	1 6	912		...
15	Hercules	C.R.	5234	3760	325 0	59 0½	21 1	3 to 9	...	...	1 0	1481		D. B. R.
16	Hotspur	R.T.	2637	1730	235 0	50 0	20 1	8	8 to 11	11	1 3	896	1	S. B. R.
17	Hydra, D.	T.	2710	...	225 0	45 0	16 6½	...	...	...	...	...		...
18	Invincible	C.R.	3774	2675	280 0	54 0	24 1	6 to 8	...	...	0 10	924		S. B. R.
19	Iron Duke	C.R.	3787	2675	280 1½	54 1	24 1	6 to 8	...	...	0 10	924		O. R.
20	Minotaur	B.R.	6643	...	400 0	59 4½	21 1	5½	...	...	0 10	1776		O. R.
21	Monarch	R.T.	5102	3615	330 0	57 6	21 1	4 to 7	...	8 to 10	1 0	1265	2	S. B. R.
22	Northumberland	B.R.	6621	...	400 0	59 3½	21 1	5½	...	...	0 10	1549		O. R.
23	Penelope	C.R.	3096	2711	260 0	50 0	...	5 to 6	...	...	0 10	688		2 O. R.
24	Prince Albert ...	T.	2537	...	240 0	48 1	...	4½	...	...	1 6	466	2	O. R.
25	Resistance	B.R.	3710	...	280 0	54 1	...	4½	...	...	1 6	607		O. R.
26	Rupert, D.	R.T.	3159	...	250 0	53 0	19 10½	6 to 11	12	...	1 0	...	1	O. R.
27	Scorpion	R.T.	1833	...	224 6	42 4½	...	4½	...	...	0 9	...	2	O. R.
28	Sultan, D.	C.R.	5234	3998	325 0	59 0½	21 1	3 to 9	...	...	1 0	1481		D. B. R.
29	Swiftsure	C.R.	3893	...	280 0	55 0	25 10½	6 to 8	...	...	0 10	...		...
30	Thunderer, D. ...	R.T.	4407	3245	285 0	62 3	18 0	10 to 12	10 to 12	12 to 14	1 6	2224	2	O. R.
31	Triumph	C.R.	3893	...	280 0	55 0	25 10½	6 to 8	...	...	0 10	...		...
32	Valiant	B.R.	4077	...	280 2	56 4	...	4½	...	...	1 6	912		O. R.
33	Vanguard	C.R.	3774	2675	280 0	54 0	24 1	6 to 8	...	...	0 10	924		S. B. R.
34	Viper	R.	737	...	160 0	32 0	...	4½	...	...	0 10	180		2 O. R.
35	Vixen	R.	754	...	160 0	32 5	...	4½	...	...	0 10	180		2 O. R.
36	Warrior...	B.	6109	...	380 0	58 0	22 0	4½	...	...	1 6	975		O. R.
37	Waterwitch... ...	...	781	...	162 0	32 1	...	4½	...	...	0 10	180		Lumley
38	Wivern	R.T.	1899	...	224 6	42 4	...	4½	...	...	0 9	...	2	O. R.
	Wood Armourclads.													
39	Caledonia	B.	4125	...	273 0	59 2	...	4½		...	2 5½	930		O. R.
40	Enterprise	C.	993	...	180 0	36 0½	...	4½	...	...	1 7½	195		O. R.
41	Favourite	C.	2186	...	225 0	46 9½	...	4½	...	...	2 2	560		O. R.
42	Lord Clyde	B.R.	4067	...	280 0	58 11	...	4½ to 5½	...	...	2 7½	1379		O. R.
43	Lord Warden ...	B.R.	4080	...	280 0	59 0½	20 9½	4½ to 5½	...	...	2 7½	1379		O. R.
44	Ocean	B.	4047	...	273 1	58 5	...	4½	...	...	2 5½	941		O. R.
45	Pallas	B.	2372	...	225 0	50 0	16 6	4½	...	...	1 10	560		O. R.
46	Prince Consort ...	B.	4045	...	273 1	58 5	...	4½	...	...	2 5½	941		O. R.
47	Repulse...	B.	3749	...	252 0	59 1½	...	4½ to 6	...	...	2 7	1043		O. R.
48	Research	C.	1253	...	195 0	38 6	...	4½	...	...	1 7½	352		O. R.
49	Royal Alfred ...	B.	4068	...	273 0	58 7	...	4½ to 6	...	...	2 5½	950		O. R.
50	Royal Oak	B.	4056	...	273 0	58 6	...	4½	...	...	2 5½	930		O. R.
51	Royal Sovereign	T.	3963	...	240 7	62 0½	...	5½	...	...	3 0	560	4	O. R.
52	Zealous	B.	3716	...	252 0	58 7	...	4½	...	...	2 6½	791		O. R.
	Iron Cruisers.													
53	Active	B.	2322	1650	270 0	42 0	15 2	...	...	...	...	...		O. R.
54	Blonde, D.	B.	4245	...	342 4	51 4	...	...	...	...	...	...		...
55	Inconstant	B.	4060	...	337 4	59 3½	17 5½	...	...	...	...	...		S. B. R.
56	Raleigh, D.	B.	3211	...	298 0	48 6	16 1½	...	...	...	...	...		O. R.
57	Volage	B.	2322	1650	270 0	42 0	15 2	...	...	...	...	...		O. R.
	Colonial. *Iron Armourclads.*													
58	Abyssinia	T.	1854	...	225 0	42 0	12 3	6 to 7	7 to 8	8 to 10	0 10	...	2	O. R.
59	Cerberus	T.	2115	...	225 0	45 1	16 6½	6 to 8	8 to 9	9 to 10	...	...	2	O. R.
60	Magdàla	T.	2107	...	225 0	45 0	16 6½	6 to 8	8 to 9	9 to 10	0 10	851	2	O. R.
	Great Eastern...	...	...	...	692 0	83 0	...	...	...	...	...	...		O. R. {

* The draught, area of midship section, and displacement given above are those the vessel had when according to the design of Captain C. P. Coles, C.B., and Laird Brothers, they should have been

THE

ANNUAL

OF THE

Royal School of Naval Architecture

AND

Marine Engineering.

A COLLECTION OF PAPERS ON PROFESSIONAL SUBJECTS CONTRIBUTED BY MEMBERS OF THE PRESENT AND FORMER SCHOOLS OF NAVAL ARCHITECTURE.

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1872.

TABLE OF CONTENTS.

The present number of the *Annual* has been published under the direction of the following Committee:—

J. H. COTTERILL, M.A., *Vice-Principal of the School.*

JOHN BLACK, *Student of the School.*
RICHARD JAGO BUTLER, *Student of the School.*
WILLIAM JOHN, *Fellow of the School.*
ALBERT EDWARD SEATON, *Student of the School—Secretary.*
GEORGE STANBURY, *Fellow of the School.*
ADRIAN VIZETELLY, *Associate of the School—Editor.*

MR. C. W. MERRIFIELD, *Principal of the School, has kindly acted as Treasurer.*

All suggestions and contributions for the next number should be addressed to the Editor of the *Annual*—Royal School of Naval Architecture, South Kensington, W.

ANNUAL

OF THE

ROYAL SCHOOL OF NAVAL ARCHITECTURE

AND

MARINE ENGINEERING.

INTRODUCTION.

In laying before the public this the second number of the *Annual*, it may not be out of place to advert briefly to the considerations which led to its publication last year. As was then stated, it was felt that, in various parts of the world, facts and opinions, calculated to interest Naval Architects and Marine Engineers, were being brought under the notice of many of those who had been educated at the School, and that it would be very desirable to have some organ in which such facts and opinions might be recorded. The success attained by the first number has encouraged the production of this, which, it is hoped, will be found in many respects superior to the former.

Although this number is considerably larger than the previous one, it has been kept within its present limits only by withholding some interesting communications; but, much as the necessity for this is to be regretted, it was thought important to avoid giving ground for the suspicion that the size of the *Annual* might be increasing more rapidly than its quality. At the same time it is hoped that the publication is

far from having reached the size or standard of excellence it may yet attain.

The hope expressed in the last *Annual*, that the members of former Schools would sympathise with "the attempt to popularise the treatment of subjects too often enveloped in technicalities, and aid it by contributions," has been realised, and this *Annual* contains articles from the pens of three gentlemen, formerly members of the Central School of Mathematics and Naval Construction at Portsmouth.

Last year elaborate Tables were given of various particulars concerning the Ironclads and Iron Cruisers of the Royal Navy, and it was intended to have published in the present number equally minute particulars of the Foreign Ironclad Fleets. This information has been to a large extent collected, but it is not yet quite complete, and it has been thought advisable to delay its publication rather than to give it in an imperfect form. With a view to the appearance of these Tables next year, the Committee will be glad to be favoured with any reliable data likely to be of use in preparing them.

The Committee have been solicited on all sides to publish complete sets of the examination papers for the diplomas of Fellow and Associate of the School. Looking to the endeavours now being made to promote the spread of technical education, such a publication would possibly not be without interest, but the Committee fear that on the present occasion it would involve too great an encroachment upon the space placed at the disposal of contributors.

South Kensington, December, 1871.

ON THE VALUE OF SCIENCE TO SHIPBUILDERS.

BY E. J. REED, C.B., VICE-PRESIDENT OF THE INSTITUTION OF NAVAL ARCHITECTS.

WHEN Sir John Pakington, Bart., a former First Lord of the Admiralty, was recommending, and His Grace the Duke of Somerset, the then existing First Lord, was favourably entertaining, the establishment of the present Royal School of Naval Architecture and Marine Engineering, of which this *Annual* is the organ, it became my duty, as Chief Constructor of the Navy, to thoroughly consider the matter, and to show what grounds existed for carrying out the project. My experience of the Admiralty Office and of the Royal Dockyards left me no room to doubt the desirability of, I may even say the pressing necessity for, such a School; but in order to fortify my opinion, and to lay down the most solid basis of fact for my advice, I addressed letters to the principal shipbuilding firms of the country, inquiring what means, if any, existed for giving a sound scientific training to their students and apprentices. I will not say that the result was to show that no such means existed, for that would be to reflect unfairly upon some few very humble and limited efforts which were being made; but I may confidently state that nothing like a sufficient and satisfactory School of Naval Architecture existed in any part of Great Britain. The need of trained Naval Architects must often have been felt, but it had not been sufficiently felt and understood to lead to effective action. I fear that even in the long interval which has since elapsed but little improvement in this respect has been made in the provinces. As an indication of this, I may mention that when distributing prizes to the Liverpool School of Science in October last, I ascertained that the strong desire of the officers of that school to establish classes in Naval Architecture had been frustrated by the inability of the Council to secure the services of a thoroughly competent teacher of the science. These and other circumstances point to the

desirability of still exerting ourselves to spread a knowledge of the value of scientific training to Naval Architects and shipbuilders.

I confess that upon me the value of scientific knowledge to the profession becomes more and more impressed every day, and that, too, whether one's engagements direct his thoughts predominantly either to the great features of naval design, or to the details of shipbuilding work. In both the necessity for, and value of, a scientific grasp of the work are very great—so great that all those students of the Royal School who combine good professional knowledge with good and sterling qualities of character have an ample field for professional enterprise and success open before them.

Let us first consider the present state of affairs in the Royal Navy. It cannot be doubted that a cloud of discredit lowers at the present moment, at least to some eyes, over certain ships of the Royal Navy. But how has that been brought about? Most assuredly not because the authorities of successive Admiralties have adhered too closely to the line chalked out by their scientific advisers; but, on the contrary, because that line has been too widely diverged from under the pressure of persons who were ignorant of the science of naval construction. Until the Navy, the Press, and the Parliament urged the Government to withhold their confidence from their scientific advisers so far as to build the *Captain*, and to insist on the construction of other low-freeboard ships, was there any shadow of a ground for want of confidence in H.M.'s ships, except in so far as the use of iron armour and of huge guns had rendered unavoidable? The whole strength of the scientific advisers of the Admiralty, from the date of the *Warrior's* design to that of the *Captain's*, was exerted in favour of high-sided, seaworthy ships, and against Monitors and dangerous vessels of every form. At length the action and the agitation of the unscientific begat so much confidence, even in the minds of the highest political and naval authorities, that some concessions became imperative, and there is reason to fear that but for the (in one sense timely, although in another sense untimely) loss of the *Captain*, men of science would have been completely overruled, and the future iron-clad Navy would have been constructed in violation of scientific principles. That loss quelled for a time the dangerous agitation, and to a large extent set the hands of scientific men

free, although the general ignorance of the underlying principles of the subject still blocks the path of the constructor with many obstacles. Still, if the future of the Navy is to be a safe and satisfactory one, it can only be made so by the perpetual observance of the settled principles of science, and every improvement must be made with careful regard to those principles, and to such further knowledge as further scientific inquiry and experiment may unfold.

The very same considerations apply to the improvements which have been made, and which remain to be made, in the detailed construction of our iron-built ships of war. The primary object of a war-ship constructor, as of the constructor of every other ship, is to obtain his speed, strength, carrying power, &c., with a minimum weight of material. Now the improvements made in this respect have been greater in the British Royal Dockyards than anywhere else. Lloyd's have done much to improve mercantile iron shipbuilding; and the Liverpool Lloyd's have done much also. In a few cases the steps taken will, in my opinion, have to be in some degree retraced—so great has been the disposition of certain authorities to set the builder and owner free from excess of weight. But nowhere have improvements been carried so far, or worked out so judiciously, as in the Royal Navy, owing to the high scientific education of the Admiralty staff. I will not disclaim all credit for myself in this matter, for it is one to which I have given much anxious attention; but much more is due to the fact that my staff of colleagues and assistants embraced such highly-educated officers as Mr. Barnaby, Mr. Barnes, and Mr. Crossland, all of whom are masters of the art of getting the maximum strength in a ship out of the minimum of material. It will be quite easy to illustrate the truth of the position which I have taken up in this paragraph by references to many various details of construction; but I will mention only the very important one of the proportioning and disposition of rivets. I am quite sure, after carefully comparing the riveted work of the private and public shipbuilding establishments of this country, that there is a very marked superiority in these respects in the Royal Dockyards, the number of rows of rivets, which in former days was very often deficient, being now very often in excess, in the practice of private firms. In short, the scientific regulation of

the work is very defective in the latter establishments, and the practice there is much too inferential and imitative. I might say the same thing of many other features of construction—more especially, perhaps, of such special features as result from breaks in decks, where the special strength is often so provided in private yards as to result in the concentration of great strains upon one or two neighbouring spots, and in consequent weakness, and not unfrequently in fracture.

We have thus already been drawn into the consideration of some points connected with the building of mercantile steamers; but when we turn more exclusively to them, a number of unsettled problems requiring the intervention of science crowd upon us. The proportion of length to breadth which should be given to cargo-carrying steamers, the variations in this proportion which are proper in passenger vessels, and the manner in which this proportion should vary with variations in the speed required, are among the more pressing of these problems. The practice of the private trade is extremely unsettled at present with reference to these points, some owners and builders systematically exceeding ten breadths in length, others as systematically keeping to about nine breadths, and others, again, viewing even the latter proportion as extreme and dangerous. I do not mean to imply that the most careful application of existing science would afford a demonstration of the superiority of any given proportions in all cases, and assuredly the best proportion for one size of ship would be found not the best for ships of other sizes; but there *are* questions involved which science undoubtedly could settle, and among these I place the best proportions for given sizes and speeds, and the best distribution of strength for these proportions.

All this is true even while we consider only the construction of ships in *iron*, the relation of form and proportions to other elements of construction being in a most undeveloped condition; but it will become still more true the moment the construction of *steel* ships comes into vogue; for, just as it is absurd to build a ship with thick sides of armour of the same proportions as a ship with thin sides of sheet-iron, so it will be absurd (although in a less degree) to build ships of iron and steel of like proportions to each other, especially if we so make and manipulate the steel as to get from it both under extension and compression, say,

40 per cent. more strength than from iron. I have recommended this subject for the investigation of scientific men in papers read at the Royal Society and the Institution of Naval Architects, and in a chapter "On the Forms and Proportions of Iron-Clads," in my work upon iron-clads,* and have there shown that it is not by any means a mere abstract question, but one of the most pressing public interest, as regards both the efficiency and the cost of ships, making a difference of more than £100,000 in a single vessel.

If we turn to the question of the rolling of ships, we here again find an ample field both for the application of what we already know and for further scientific inquiry. It is the fashion to speak of the rolling of our iron-clads only, but those who have been much to sea know very well that the rolling of mercantile vessels, and even of vessels designed exclusively for passenger service, is altogether excessive and unbearable. Our Channel steamers are horrible examples of the incompetence of our shipbuilders to remedy this most obvious and injurious defect, and are, in fact, a national disgrace. Mr. W. Froude's investigations and experiments with deep-bilge keels are, in my judgment, preparing the way for a general remedy for this evil, but its present existence and its long endurance illustrate the necessity for further applications of science to Naval Architecture, for if anything short of scientific knowledge could have furnished the remedy, it would probably have been provided long ago.

The machinery for propelling ships affords scarcely less scope than the ships themselves for the advantageous application of scientific knowledge. The consumption of fuel in the marine engine has in a very few years been brought down from more than 4lbs. per indicated horse power per hour to from 2¼lbs. to 2½lbs., and when we remember that the barbarous system of shovelling coals into the furnaces by hand still obtains, it can hardly be doubted that great improvements, even in economy of coal consumption, yet await us. And when we turn from coal to the various liquid combustibles which offer themselves for use afloat, and which

* *Our Iron-Clad Ships: their Qualities, Performances, and Cost. With Chapters on Turret-Ships, Iron-Clad Rams, &c.* (London: Murray, Albemarle-street.)

lend themselves so much more readily than coal to economical combustion and use, our interest in the application of science to this subject becomes still further stimulated. Nor is it in the *production* of steam only that we are entitled to expect advantage from improved scientific knowledge, the *use* of the steam furnishing an equal opportunity for improvement.

One thing must be borne in mind, although I do not remember seeing it mentioned by any former writer—I refer to the dependence of many of the worst features of steamship practice and of seafaring life upon the undeveloped state of the marine steam-engine. Improve this; increase—multiply, if possible—the power now derived from a given *weight* of engine and fuel, and you will revolutionise the whole system of our steam transport, and sweep away the rude system of floating our sea-passengers in the turbulent wave-surface of the sea, instead of rendering available (for our personal transport at least) the smooth water which underlies, and the comparatively smooth air which overspreads, it. With very light engines of great power this object may easily be accomplished, and its accomplishment will be one of the greatest achievements of practical science.

Naval architecture and marine engineering are thus seen to abound with occasions for the useful application of scientific knowledge, and shipbuilders of every class may profit largely from its acquisition and employment. At the present moment their trade is in the most prosperous condition, the demands for iron steamships just now far exceeding those of all former times, partly owing to the opening of the Suez Canal, and partly (and, as I think, much more) owing to the number of new fields for steam transport which the reduction of fuel-consumption in the marine engine has opened up. Let this prosperity be made, as it ought to be, the occasion of improving as well as of extending the shipbuilding art, by bringing the light and the power of science to bear upon it; and let those gentlemen who plume themselves too exclusively upon their supposed *practical* skill, and still more those who affect to look contemptuously upon men trained in the science of their profession—let those gentlemen remember, that the simple meaning of "Science" is KNOWLEDGE, and the meaning of want of science is Ignorance, and that the shipbuilding art is one which it would be fatal to abandon to the ignorant only.

FROM WOOD TO IRON IN SHIPBUILDING.

The history of Naval Architecture will always be an interesting topic both to professional and unprofessional readers in a country so distinctly maritime as ours, and whose safety has ever rested in her being able to maintain the sovereignty of the seas. This history has been traced in an interesting manner by several authors, from the time of the ancient civilisation up through the early periods of the history of our own country to the present day, and they have shown how, with the progress of time, changes were wrought in the form, type, and size of ships, as well as in their mode of propulsion. But this history, until a comparatively late date, refers principally to externals, and has little or no reference to the question of improvement in the art of construction. This deficiency is, however, explained by the fact that the history of structural improvement in ships in our own country does not date back more than a few centuries, for it was not until about the middle of the sixteenth century that shipbuilding as an art came into any prominence, or that any great strides were made in ship construction, or that there was any attempt to apply to the art the principles of abstract science. It was by Sir Anthony Deane and the different members of the Pett family—a family which during a long period supplied architects for the Royal Navy—that the greatest improvements were effected in shipbuilding, and their ships in point of appearance are but little different to our more modern designs.

As time went on, our ships of war increased in dimensions and in the weight of armament without any means being taken to increase the strength of their hulls, until about the beginning of the present century, when the subject was forced upon the attention of Naval Architects by the fact that all the large ships of the Navy showed signs of excessive weakness, which had afterwards to be partially remedied by clumsy and unsightly methods. It was at this time that Sir Robert Seppings, whose name is so intimately connected with the subject of structural

improvement in ships, introduced those methods for stiffening the hull the principles of which, in some form or other, have since been universally adopted in the construction of wood ships.

Regarding the latest additions to our old wooden unarmoured fleet as structures made up of an immense number of component parts, and built of a material which offers peculiar difficulties to its effective combination, there can be no doubt that in the method of building those ships, of arranging and combining the various pieces, and of uniting the whole into one comparatively rigid unyielding structure, we had arrived at a very high degree of perfection. The difficulties to be overcome in a case like the above may perhaps be imagined if we remember that, even when floating in still water, a ship is subject to great strains, arising principally from the fact that every part of her is not water-borne, and that therefore the ends are to a great extent hanging to the middle portion; but especially is this the case when the ship is floating among waves, in all kinds of positions, upright or inclined, sometimes supported at the ends, and unsupported at the middle, and *vice versâ.*

And herein, as has been remarked by a well-known author in shipbuilding, lies the greater difficulty of the naval over the civil architect. The latter has to design a structure which shall support a given load, the strains resulting from which can be made the subject of at least approximate, if not absolute calculation, and this structure must remain stable under the action of certain natural forces, as wind, solar heat, &c., the effects of which are also known, and can also be made the subject of calculation. The Naval Architect, on the other hand, has to design a structure to float in an unstable and yielding medium, and which shall be subjected to enormous and ever-varying strains, the duty of resisting which, even if they could be absolutely calculated, he could scarcely apportion in detail among the parts of his structure, as from the various positions a ship may take in a troubled sea, he would hardly know which to call the top or which the bottom of it. So that every part of a ship must be prepared to resist at different times strains of entirely opposite characters.

It was to the correcting of the evils resulting from these great strains to which the ship was continually subjected that the progress of structural improvement tended, the most marked of

these evils being the straining of the ship longitudinally, causing the ends to drop and the keel to become arched up, technically termed hogging, and which resulted in the racking and weakening of the whole structure. These evils were combated in a scientific, and, to a great extent, in an effectual manner by the introduction by Sir Robert Seppings, sometime Surveyor of the Navy, of the well-known principle of diagonal trussing; and we have only to consider for a moment the construction of wood ships to see at once what a necessary and important part this trussing must play in strengthening the structure.

An ordinary wood ship is composed of transverse ribs, covered on the outside and inside with strakes of planking running longitudinally or at right angles to the ribs, with the edges free to slide upon each other, the fastenings being of course at the intersections of the two sets of timbers. Now such a structure as this is made up of a number of elementary four-sided figures, formed by these two assemblages of timbers, and, as we know, any four-sided figure may be made to change its shape while the length of the sides remains unaltered; but if we introduce another piece from one corner to the opposite one, we have fixed our structure unalterably to a certain shape, from the fact that we have now two triangles, and that there cannot be two triangles on the same base and on the same side of it, and having their other sides respectively equal. The tightness of the fastenings and the caulking of the seams would of course offer a certain amount of resistance to the racking action, though not sufficient to resist the whole, as experience has proved. We see, then, the advantages to be gained from the application of the principle of diagonal trussing to a ship's frame. This principle was applied in practice by working on the inside of the ship's frame a combination of massive timbers, composed, firstly, of a series of timbers or riders placed at an angle of 45° with the timbers of the frame, and with their upper ends inclining *towards* the extremities of the ship; secondly, of longitudinal pieces abutting into these; and, thirdly, of trusspieces, placed on the diagonals of the rhomboids formed by the two former sets of timbers. Subsidiary series of diagonal trusspieces were also worked between the decks. This system was applied to line-of-battle ships; for frigates a combination of iron plate riders and continuous longitudinal strakes was adopted.

A modification of these systems was introduced more recently—viz., a series of diagonal iron plate riders with their upper ends inclined *from* the extremities, combined with a series of wood trusses worked at right angles to them and with their heads and heels abutting into the continuous strakes of planking which formed the longitudinal ties—viz., the clamp above and the binding strakes below; one great advantage of the plate riders being that they could be carried up behind the shelf pieces as high as required.

The system of diagonal trussing was, at its early introduction, employed for strengthening ships already built, and which had shown considerable longitudinal weakness, by the fitting of diagonal struts between the heads and heels of the pillars in the holds, the result being more favourable than was anticipated.

The above means for strengthening our ships were supplemented by the filling in solid of the openings between the timbers in the bottom of the ship, by introducing thick waterways and shelf pieces, and carrying these timbers from end to end of ship with as little diminution of strength at their abutments as possible, by well supporting by means of coaks the butts of the wale planks, by preserving as much as possible the continuity of the deck planking, and by a judicious arrangement of the "shift of butts" and of the fastenings throughout the ship generally.

It was by these and other means that the Naval Architect had succeeded in uniting a vast assemblage of timbers into one structure which should be comparatively rigid and unyielding under the influence of the heavy strains to which it would be subjected; and to show to what extent a rigid structure had been obtained, we may remark that our largest frigates would not break more than from 2 to 3 inches, while before the introduction of the improvements we have mentioned it was no uncommon thing to find a ship "hogged" to the extent of 2 feet or more.

We have not space to discuss the means which had been employed to remedy the weakness resulting from certain local strains to which a ship was continually subjected. Suffice it to say that the results which were obtained by the adoption of diagonal trussing in ships, and the other means we have mentioned, testify to the correctness of the principles which had guided the Naval Architect in strengthening his ship, and also to the perfect character of the workmanship; for we must remember that open

butts, or ill arranged or loose fastenings, or badly caulked seams, would make all the difference between a strong and a weak ship, and that no skill in the application of principles could compensate for carelessness in the workmanship.

From wood to iron was a great stride, and constituted a complete revolution in the art of shipbuilding, owing to the fact that these materials entirely differ from each other in their general characteristics, absolute strength, mode of working, the extent of their application, and, more than all, in their capabilities for effective combination. At the same time the change from the one to the other was rendered more difficult from the fact that those who had been accustomed to design and build in wood knew very little about iron, and those whose knowledge of and experience with iron was more extended knew but little about the requirements of a ship. Shipbuilders had, therefore, to learn over again the rudiments of their profession, and to divest their minds of various ideas and prejudices which belonged entirely to the old state of things. Consequently we find, as we should expect to find, in the earlier specimens of iron ships a lingering fondness for the old material, and an evident desire to retain it in some form or another as long as possible, this desire often resulting in combinations which were productive of weakness rather than strength. We find, too, in the early specimens of the use of iron for shipbuilding purposes an evident ignorance of the capability of the material, manifested in the unmethodical manner in which it was disposed and the unnecessary amount of it employed; weight appearing to have been, in the mind of the builder, synonymous with strength. Time and experience has, however, developed more correct ideas regarding the material, and greater confidence in it, and this has resulted in a general reduction of scantlings. As an example of this, Lloyd's rules and tables of scantlings for iron ships have recently been considerably modified, to meet the existing state of knowledge in iron shipbuilding.

Again, we find instances in most of our early iron ships of great trouble and expense being incurred in order to assimilate certain portions of the structure to the form of corresponding portions in a wood ship, when no advantages whatever were to be gained by such a course, as, for example, in rabbeting the keel, stem, and sternpost, a system which shipbuilders found to be in many cases expensive, and attended with few, if any,

corresponding advantages, and which therefore soon fell into disuse.

It will be seen at once that the employment of iron in lieu of wood materially modifies the relative importance of certain parts of the ship's structure, and in some cases renders obsolete in the one what was of the greatest consequence in the other. The most apposite illustration of this is, perhaps, the case of the absence in iron ships of iron riders, and every other embodiment of the principle of diagonal trussing, which we have seen was an all-important consideration in the strength of a wood ship. These are unnecessary in an iron ship, from the fact that the edges of the skin plating are rigidly connected together, and therefore resist better the racking action to which the ship is subjected. Or, to put the case in the quaint words of a well-known shipbuilder, "Strike a line in whatever direction you please across the skin of an iron ship, and there you have a diagonal rider."

We must admit, as shipbuilders, that we are greatly indebted to the engineers of our day for having shown us what can be done with iron, especially in those magnificent structures, the various railway and other bridges which have been erected in this and other lands, and which now stand as some of the grandest monuments of engineering skill. The results of the experiments which naturally preceded and accompanied the erection of those structures gave us much valuable information about iron, as have also the various series of experiments which have been carried out by the Government or by private individuals.

We may remark also that these iron bridges bear as much analogy to a ship as a structure fixed on land can well bear to another which has to float upon the yielding wave. In fact, the consideration of the ship's hull as a hollow iron girder, and the arrangement of its parts on the same principles as those which would govern the proportions of a girder, has now become a favourite idea, and that it is a correct one all must see who reflect for a moment upon the positions which a ship must sometimes assume when travelling across waves.

A ship was first viewed in this light by Sir William Fairbairn, a well-known engineer, and a pioneer in iron shipbuilding. He pointed out the necessity of concentrating the material in the upper and lower parts of the ship, as in a well-

formed iron girder, to enable it to stand the alternately pulling and crushing strains to which those parts would be subjected when the vessel was passing across waves. He also found that in actual specimens of iron ships the top of the girder was usually weaker than the bottom, and recommended the introduction of hollow iron girders under the deck beams among other means for strengthening this part of the structure.

It is to be feared that the weakness of the upper works in most of our early iron ships, together, perhaps, with the use of bad iron, was the cause of the loss of many a noble ship and hundreds of human lives. On this point we may refer to some very instructive examples of weakness in iron ships, and the means adopted for remedying it, given in *Shipbuilding in Iron and Steel*, by Mr. E. J. Reed, C.B.

The introduction of iron gave greater scope for improvement in the methods of constructing a ship's frame, and accordingly we find that departures have been made from the purely transverse method, as it is termed, which was universal in all wood ships of any size. Mr. Scott Russell was the principal introducer and advocate of the longitudinal system of framing, of which the *Great Eastern*, *Annette*, and other vessels built by him may be taken as fair types. In this system the principal girders of the frame are made continuous in a fore and aft direction, with short transverse frames between them.

In the designs for the iron armour plated ships of the British Navy a combination of the transverse and longitudinal systems has been adopted, and the full advantages of each thereby obtained. The longitudinal frames are constructed of a number of iron plate-girders running continuously in a fore and aft direction from one end of the ship to the other, combined with a system of transverse frames running continuously across the keel, the spaces between the longitudinal girders being filled in with light bracket frames to stiffen the girders and to support the bottom plating. By this method, in combination in our later ships with a complete inner as well as outer bottom, the maximum of strength has been obtained with the minimum of material; and, with a marked lightness of structure, we have a structural strength which in actual trials at sea in heavy weather has proved more than equal to withstand all the strains which the ship has had to bear.

There is, however, one danger connected with this *cellular* system of construction—viz., that while it gives us the power of reducing our framing to the extreme of lightness, at the same time preserving great structural strength, it tempts us to pass the limits at which the necessity of retaining proper *local strength* makes it imperative that we should stop. That this limit has been reached in some of our latest iron-clad ships many people who have had to do with them believe.

In this age of progress we can accept nothing as final, and already we may perceive symptoms of another change in the material for shipbuilding by the use of steel; and although steel is but iron in another form, yet its general application would make radical changes, and be the commencement of a new era in shipbuilding. This question of iron *versus* steel is becoming a subject of debate between the shipbuilders on the one hand, and the iron manufacturers on the other. The latter assert that they can make, and are making, a material which they call steel, and which, while being capable of bearing a tensile strain nearly or quite double that of good iron, possesses at the same time all the other qualities of ductility, elasticity, &c., which we have been accustomed to expect in a good iron; while the former maintain that their experience with this material has not been of that encouraging character to lead them to adopt it entirely, or even to use it at all without great caution. With whatever modification we accept the statements of either side in this controversy, one thing is certain—viz., that if ever iron manufacturers are able to produce a material which shall be proportionately as cheap as iron, and of double the strength, and which shall at the same time possess all those properties which we can get with good iron; and if this material, when subjected to the most rigid test, shall prove itself worthy of the confidence of the shipbuilder; then, whether it goes by the name of steel or any other, it will as certainly supersede our present iron for shipbuilding purposes as iron has superseded wood; although, of course, the change would involve no such revolution of ideas as we have seen necessarily accompanied the change from wood to iron in shipbuilding.

H. E. D.

TECHNICAL EDUCATION OF NAVAL ARCHITECTS.

By W. Gowings, Fellow of the School.

Technical education in different mechanical professions has of late been attracting much attention from men of all classes, and the definite action already taken by some of the foremost statesmen, philosophers, merchants, and manufacturers, seems to promise that the matter will not be allowed to slumber or entirely die away. That special training in special subjects is not only highly desirable, but absolutely imperative on those who are to carry on our great manufacturing enterprises, can hardly be doubted, for our rivals in other nations are assiduously cultivating all the native talent and genius they possess to outstrip us in the race of life, and beat us in our own markets, even in the specialties which hitherto have been almost peculiar to our country. Not possessing our great advantages of iron and coal—at least not to such an extent as to produce formidable rivalry from that source alone—they have endeavoured by every means in their power to compensate for that deficiency, and, by careful training and study in the scientific application of means to an end, obtain results which can vie with, or surpass, ours in efficiency and cheapness.

Chief among our competitors are Germany and France, who are making rapid strides in the mechanical arts—probably in none more so than in iron manufacture and shipbuilding, which are now so intimately connected. The former country has long had a system of education which renders her people peculiarly fitted to apply discoveries in arts or science to the ordinary occupations of life; while in France the trained students of the Ecole Polytechnique spread throughout the country sound scientific principles which they adapt to their various trades and professions. Amongst other subjects the science of Naval Architecture has occupied the attention of the French, and the theoretical training in that study which the students receive seems to be highly

appreciated by the Government and shipbuilders of France, as they are usually sought after and engaged before completing the whole of their educational course. This high estimate of scientific attainments contrasts strongly and favourably with that of our own country, and when we consider that the whole of our commerce is carried on by our ships, it seems strange that we should not have emulated our neighbours in fostering that art which has made England what she is.

It is true that, as a nation, we do not extend State aid towards any purely commercial undertaking, but shipbuilding can scarcely be regarded in that aspect alone, since for imperial purposes it is necessary to maintain our fleets in the utmost efficiency, and whatever conduces to that end is a benefit to the community at large. It is a subject of vital importance to the future welfare of our country that the care of her Royal Navy, at least, should be in the hands of perfectly competent men—men trained to determine theoretically what are the most advantageous types for modern vessels of war, and capable of putting their theory into practice, so as to obtain the maximum of efficiency and safety at a minimum of cost. Much has been said and written of late, by men of no practical or scientific training, as to what is best for our Navy, and the proper way of arriving at that most desirable of results; but in many cases their utterly unscientific reasoning, their crude surmises, and evident ignorance of their subject, show how great is the want of information on this matter, although their plausible statements and deductions therefrom are apt to impose upon general readers who are incapable of detecting their fallacies. Hence the necessity of having men at the head of the Constructive Department of our Navy who from previous education are thoroughly capable of dealing with the ever-varying demands on their ability and skill, and this can only be attained by the Admiralty making provision for the special training of their Constructors, so that the nation may rely upon having the services of those best qualified for the work. On two previous occasions such provision has been made, but unfortunately they were only half-hearted measures, and of comparatively short duration; still they have borne good fruit, and considerable benefit has resulted from them. In 1810 a College of Naval Architects was established at Portsmouth, but the students, after receiving an education specially fitting them

for positions in the public service, were neglected for years, until it was found necessary to call upon them for advice as being most competent to give it. Messrs. Creuze, Read, and Chatfield, former students of that college, were commissioned by the Admiralty in 1842 to report upon the requirements of the best types of ships for the Navy, and, complying with the demand upon their services, they eventually sent in an exhaustive report which met with official approbation, and demonstrated the advantages which their previous education had conferred on them.

At the time of their report, however, the college at which they had been trained had disappeared, having been abolished in 1833; but no sooner were they in a position to command attention to their views than they endeavoured to resuscitate it, fully appreciating the benefit which the public service would obtain from men educated similarly to themselves in the scientific branch of the profession, and they ultimately succeeded in their aim. In 1849 a central School of Naval Architecture was established at Portsmouth, and although it only lasted for a few years, being closed in 1853, the results accruing from it have become very evident. In addition to gentlemen now holding various responsible positions in the Royal dockyards, the members of the present Council of Construction at the Admiralty, and the late Chief-Constructor, Mr. Reed, were students there, and though differences of opinion may exist as to the *amount* of benefit the country has derived from their services, there can be little doubt amongst practical shipbuilders that they *have* done good service to the State at an important time.

These instances tend to prove the benefit which the Royal Navy must obtain from the introduction of specially trained men into the Constructive Department, nor can there be room for doubt that equal advantages would accrue to the Mercantile Marine from the services of similarly educated men. Our shipbuilders of the present day produce vessels possessing many excellent qualities, but doubtless this excellence can, and will be, enhanced, especially when their designers and shipbuilders generally possess more scientific and theoretical knowledge than is now the rule. Their motto seems to be "*Experientia docet,*" and this might be inscribed over every successful shipbuilding establishment. But the teachings of experience are equally as slow as they are sure, and the dim gropings after excellence may

be greatly expedited by the light of theoretical considerations. Of course it may be said that the skilful Naval Architect is by this time fully aware of what is the best sort of ship to do certain specified work, and that you need only tell him what you require to have it. But, excellent as are present results, it must be a very confident man to say they cannot be improved; and when we remember the complete change the introduction of steam and iron has occasioned in ships, and the possibility of further advances in the present means of propulsion, or even the discovery of new motive powers, it behoves us to prepare for the calls which the future will most certainly make upon our profession. Technical education will do much to help us in this respect—it will enable us to say beforehand what we *can* do—to predicate with a great degree of certainty what we *may* do, and by providing us with theories, founded on true scientific bases supplemented by experience, enable us to estimate with greater accuracy the advantages or disadvantages of future proposed improvements.

Until very recently the art of shipbuilding as practised in many private yards was extremely rude. In some cases a half model would be made to eye, and alterèd here and there until it appeared suitable for the purpose—the practical experience of the builder being his only guide; no drawings were prepared, no calculations made as to the tonnage, displacement, or draught of water, but everything depended upon a practised eye and mature judgment. Then, instead of laying-off the vessel on the mould loft floor, sections would be made to the model, and from these the frames of the ship would be prepared, the sections being measured to scale. When the frames were in place, the timbers would be faired by dubbing-off the projections both outside and inside, and sometimes this would lessen the sizes of the timbers to a very considerable extent, rendering the vessel dangerously weak. Rougher modes of building than this, even, were practised until very recently, and sometimes where draughtsmen were employed to design or lay-off vessels, they were completely ignorant how to calculate displacement, tonnage, or any other element which is now considered essential for the completion of a design. Evidently the building of ships on such a method—or want of method—could only be entrusted to very experienced men, while progress in shipbuilding, as a science, must have been extremely slow. For more enlightened and educated minds,

however, the publication of Simpson's rules in the middle of the last century, and the later researches of Chapman and others, provided surer means of performing their work, while continued advances in theory, combined with deductions from experience, have at length brought Naval Architecture to its present great perfection. In these days the young shipbuilder, instead of having to trust to the results of his own observation, can resort to professional works for information on many subjects of which his predecessors were ignorant, and by his own industry and perseverance may obtain much valuable assistance in his career, although not to the extent which a special training would confer on him.

The general routine in shipbuilding establishments is not such as to produce highly scientific men. A lad goes into the office, copies drawings, makes some of the more simple yet indispensable calculations, and generally acquires a knowledge of his profession as best he can—the more observant and industrious he is, the more versed he becomes in his art. But direct instruction in the higher branches of the subject is rarely accorded him, for while spending time in such a manner other work must be put aside, and this can seldom be permitted. Hence, when called upon to design a vessel, he must rely upon some good type of the ship required, and make his own as like it as circumstances will allow. This, in general, is as good a plan as can be pursued, but when some novel design is required—and the exigencies of modern commerce and progress will make this more common than formerly—he cannot fall back on scientific theories to fortify the conclusions which his experience may enable him to arrive at, and however firm may be his *belief* that he has compassed his end, yet he lacks more certain modes of testing it.

One other side of the question, however, is also worthy of consideration—viz., that from which the shipowner may be disposed to regard it. Supposing he requires a vessel which shall best fulfil certain conditions, he is entirely in the hands of the designer of his ship, and the want of technical education may result in much pecuniary loss when the vessel is afloat. Probably in a second ship of the same type faults which appeared in the first may be obviated, and growing experience may ultimately produce the best possible result; meanwhile, however,

the ship first built has not returned so great a profit as those built subsequently. It may be contended that such is always the course of progress, and that perfection cannot immediately be obtained in any case; but there is little, if any, doubt that faults which may be guarded against from the outset can be predicted by scientific calculations. Thus a vessel may be uneasy in a sea-way from faulty design or bad stowage, and both these may, to some extent, be guarded against by calculations made previously to the ship's being built, especially the former. By means of a curve of stability we can tell to what extent a ship may incline with safety, and hence a captain would have the means of knowing with some degree of certainty when he should shorten sail, for though a vessel may seem to be as safe as, or safer than, many another, yet in reality she may be in greater danger—the unfortunate *Captain* being a melancholy example. Further, when a ship is designed, certain calculations made from her drawings will give her metacentre and centre of buoyancy, points of great importance to a vessel; and after she is launched a very simple and comparatively inexpensive experiment, with subsequent calculations, will find the actual position of her centre of gravity when complete for sea, cargo being excepted. The determination of this latter point is very useful for deciding the best possible position of the centre of gravity of cargo, and thus to indicate its stowage, which information would probably be useful to the captain or stevedore. It is true that their experience *should* enable them to stow a ship properly, but we know that such is not always the case; and it is probable that many a ship has foundered from the ill-stowage which might have been avoided, had the best general position of the cargo been previously pointed out. Probably more trust may be placed in experienced men than in mathematical deductions, but if this information be given to captains with every new ship, the result may confidently be awaited, for science will eventually assert itself, and make its value felt by all concerned, whether owner, builder, captain, or stevedore. No one would pretend absolutely to dictate how to stow a vessel from purely theoretical considerations, for, in general cargoes, the nature of the different portions of the freight demands the utmost attention; but in any case they might be so arranged that the centre of gravity would most nearly approach the best theoretical position. Hence it appears highly

desirable that those who design ships shall be able to make the necessary calculations, while the additional expense they would entail would scarcely be worth consideration.

How, then, may this theoretical education be best obtained? Much may be done by persevering industry in the study of professional works, and a perusal of the valuable reports of the Institution of Naval Architects. But to appreciate and understand theoretical investigations, a special training seems most desirable. To design a ship and feel absolutely certain as to her general qualities—to comprehend and estimate the strains brought upon her under various conditions—to calculate the strengths of the several parts of the structure—to appreciate the chemical and mechanical qualities of the materials used, and their relative actions on each other—to understand the laws and phenomena of waves so far as philosophy can explain them—these, and other kindred subjects, should form the *scientific* education of the Naval Architect, while careful attention to, and intimate acquaintance with, ships in process of construction, should form his *practical* education. To attain this, a course of study in such an institution as the English School of Naval Architecture, or the Ecole de l'Application du Génie Maritime of France, would apparently be the best means, for these establishments certainly possess advantages which no amount of private study can counterbalance. Such, at any rate, appears to be the opinion of the Admiralty and the Institution of Naval Architects, as the establishment of our own school serves to prove, and there can be no doubt that in due time the country at large will reap the benefit of the public money which has been spent on that school, as it has already done for that spent on previous ones.

One part, however, of the practical education should not be omitted, if possible—the actual observation at sea of the behaviour of ships. The men who have to design and build vessels should be able to see, and judge for themselves, in what manner a ship is acted on by the winds and waves; to observe the straining actions to which the frame is subjected; to notice the parts more particularly liable to wear and tear from the action of the elements and other causes; and by this means form a better estimate how to provide most effectually against structural defects. Besides this, there is much in the stowage of stores and cargo in merchantmen, and of armament in war vessels, with which

it is well to be thoroughly familiar when dealing with designs; while a practical acquaintance with the working of the rigging, sails, &c., must also be of great value. Whatever tends to make a man more fully acquainted with his profession must be of service to him; it renders him more self-reliant and independent—more capable of sound judgment in emergency—more ready to suggest improvements of his own, or to appreciate those of others; and thus it seems far wiser to obtain information and form opinions from personal observations than to trust to those of others, and a few months spent at sea in this practical study would, doubtless, be attended with beneficial results.

There is still another consideration to be dealt with, and one of primary importance—will this superior professional education pay? Our shipbuilders may point with pride to the results they have already obtained without the assistance of highly-trained men, and argue that there is no necessity to pay the remuneration which such men would expect. But to this it may be replied that in France these educated Naval Architects are eagerly sought after; and surely if French shipbuilders find them so beneficial, English shipbuilders are likely to find the same, especially if we compare the commerce of the two countries. That foreign nations imagine such men to be valuable is proved even with the limited experience of the Royal School of Naval Architecture, for students have been sent from Russia, Norway, Holland, and Egypt to obtain the benefit of its teaching, and there seems no reason why, in our own country, this education should be less valued than abroad. Before the establishment of the English school some of our eminent shipbuilders sent their sons to the Ecole Polytechnique, considering that a liberal education at a university did not prepare them sufficiently to undertake professional duties in a shipyard, and that a special training for a special career would give them better prospects of future commercial success. Such certainly seems a wise and prudent course, and probably it will be found, at no very distant future, that the men who have been educated in both the theoretical and practical science of shipbuilding are the most capable of advancing the art, of keeping equal pace with the discoveries and inventions which may influence it, and of thus preserving to England that pre-eminence which she now enjoys, but which enterprising rivals are seeking to wrest from her.

A REVIEW OF THE PRESENT CONDITIONS OF NAVAL DESIGN, FOR COMMERCE AND FOR WAR.

BY C. W. MERRIFIELD, F.R.S., PRINCIPAL OF THE SCHOOL.

THE day of sailing ships has passed away: the leading traffic, whether of peace or of war, will never again be conducted without the aid of some other prime mover than the winds and tides. There is as yet little indication of any resting-place in the transition, and he would be a bold prophet who should venture to foretell what is to be, in the future, the leading type of vessels, either for commerce or for fight. Our navigation is in a state of transition exceeding that of mere development.

It is occasionally advantageous to pause in our active work, in order to turn round and consider our position, our objects, and our means. I think the present juncture a favourable opportunity for passing these briefly in review, and I propose to dwell especially on those points which illustrate the limits of the power and of the duty of the naval designer.

A ship is a compromise among a vast number of qualities, which, if carried separately to extremes, are incompatible with one another. The design of a ship, therefore, involves a selection from among these, both in kind and in quantity of each, such as on the whole to give the best result for the purpose intended. There is no absolute best, but only the best for the purpose. It is possible to carry out any one quality to an extreme, and it is generally not difficult to give two or three such qualities in a very high degree at some sacrifice of the remainder. Thus cargo-carrying capacity is the leading quality in a barge; while in a lifeboat seaworthiness is everything, and in a racing yacht speed. But in all other vessels, and to a certain extent even in these, a specific minimum of the other qualities of a ship must be secured, in order to give it (if I may draw an illustration from animal life) sufficient general vitality to carry out its

special function with success. These considerations practically reduce the attainable maximum of any one quality to limits which, although still wide, are far below the absolute.

The problem of the best ship is therefore an idle one, and the problem of the ship which theoretically fulfils any one quality to its absolute extreme, although conducive to a clear conception of our art, is not of much help in practical design. Our problem is a relative one—to design the best ship for a stated purpose, and subject to stated conditions—conditions and a purpose which must be as clearly understood and specifically stated as the data of any other problem which is presented to us for solution. We cannot, it is true, solve every problem which is presented to us in naval design; our actual knowledge, both of fact and of theory, is deficient in too many respects for that. Let us, therefore, begin by cataloguing what we are able to do.

In the first place, when we know the form of a ship, by means of accurate drawings, we are able to calculate with great exactness its displacement, its capacity, and all those statical properties which depend upon its mere geometrical form. To give mechanical meaning to these, however, it is necessary that we should make ourselves accurately acquainted with the distribution of the weights. Where we have the control of the stowage, as in ships of war, we can do this with a very fair degree of accuracy beforehand, especially if we take the precaution of weighing in and out all that goes over the ship's side. But even if we do not do this, the easy experimental process of inclining the ship by moving a known weight through a known space, will give us very accurately the centre of weight, if we have not calculated it, and will afford us an excellent check upon it, if we have calculated it. We are thus able, by the use of well established methods, to arrive at all the statical qualities of a ship, if we can have access to her drawings, and can perform a simple experiment just before she starts.

In the design of merchant ships we can dispense with much of this, chiefly for the reason that the designer has practically no control over the stowage, and must, therefore, so design that a considerable variation in this respect shall not be detrimental to the ship; and he must look to the master mariner to see that there is no absurdly bad stowage, and that the ship

shall be handled with some regard to the disposition of her freighted cargo.

In sober truth, the primary responsibility for the safety of a ship can never be taken off her commanding officer. Setting aside the dangers of making land, of shoal water, and of collisions, no ship can be made safe in a fool's hand, and it would be quite idle to attempt to design for that. But considering that the ocean has shores and shoals, if safety alone were in question, an exaggerated lifeboat would not make a safe ship. Speed and handiness are quite as important qualities for safety as a mere warranty against upsetting.

The dynamical qualities of a ship are more difficult to deal with, and it cannot be said that the present state of our mathematical and physical knowledge enables us to master them completely. Still we are enabled practically to get at most of what we want with a very fair degree of approximation.

We have no theoretical knowledge of the actual form of least resistance to direct motion in a resisting medium, especially in the case of a vessel which is only partially immersed. We do not know this for still water, much less for wave water.* Nevertheless we can calculate, with very respectable accuracy, the probable speed of vessels of all ordinary types, under all usual circumstances. Moreover, the proportions are generally dictated by other requirements than the simple one of the least resistance.

Rolling in wave water depends upon very varied considerations, the most important of which are the following:—

(1.) The statical stability, or stiffness, depending on the horizontal distance between the centres of buoyancy and of weight.

* A mixture of practice and theory has led us with a very fair degree of probability to the conclusion that vessels, moulded upon lines of which Mr. Scott Russell's wave system is the extreme limit in the direction of sharpness, come very near the solution of the problem. In my own opinion, his entrance is a little too sharp; otherwise I think he is right in his objections both to a cutwater and bell-bow on the one hand, and to a spur-bow on the other. For long ships, especially, I agree with him in thinking that the floor should be carried well forward, that the bow should rather tumble home than flare, and that the stem should not rake. A projecting bow, such as is in fashion at Hartlepool and Sunderland, appears to me to be not only ugly, but bad in respect of structural strength and nautical qualities.

(2.) The distribution of the weights about the centre of weight, depending upon the moment of inertia.

(3.) The form of the ship, including keels, bilges, and bilge-keels.

(4.) The harmony or discord between the proper periodic roll of the ship and the actual periodic time of the waves.

Stiffness in still water, and steadiness in wave water, instead of usually going together, are discordant and almost contradictory qualities. Stiffness practically means a tendency to keep the deck parallel to the surface; and, in a sea-way, this means parallel to a wave-surface. A ship of much stiffness, rolling unrestrictedly, will usually roll more than the waves, especially a broad, shallow ship. The question of rolling would lead us into far more matter than we have room for here, and it is sufficient to say that very great stiffness in still water is not conducive either to ease or safety in a sea-way. The best preventives (speaking generally) of heavy rolling are deep immersion, moderate stiffness, and well-marked keels, whether false or bilge-keels. While our theory of the subject is far from being complete, or capable of compact expression, we know quite enough to justify us in saying that we can build a vessel, which, if we have the stowing of her, shall very seldom roll uneasily or dangerously.

Pitching is but another kind of rolling; but inasmuch as the longitudinal section is always broad and shallow, a ship can only be prevented from pitching by being long enough to bestride more than one wave at a time. The angular extent of pitching is, however, so much less than that of rolling, that it is only abrupt pitching, like that of short, or fine-ended ships, which is disagreeably felt. At the same time, pitching takes up a great deal of the work which ought to be expended in propulsion. The ships that pitch least are long vessels, with the floor carried pretty far forwards.

As regards structural or local strength, there is no difficulty in providing for them both easily and cheaply, in the very longest ships yet constructed; nor will there be any difficulty in designing sufficiently strong for a greater length, even with a small depth or draught, provided a good, strong iron deck—not too much cut up—can be specified for.

Having thus stated, in general terms, the leading matters

within the designer's control, I turn to certain points which do not rest wholly with the Naval Architect.

In merchant ships I need only mention two points. The first is stowage. As I have already remarked, the builder can design for a certain margin in stowage; but if the ship is to be run fine in any way, either for sailing or steam performance, or otherwise, that margin must be small. No living man can design any one ship which shall behave equally well with railway bars on her floor, with unpressed cotton piled half-way up her masts like hay on a barge, or with coals or wheat. A ship must be reasonably stowed, according to her designer's intention, if he is to be held responsible for her performance.

The second point is length. Under steam, at moderate speeds (7 to 10 or 11 knots), long vessels are far more economical, per ton-mile, than short ones; but they require more careful handling both at sea and in making the land. They do not steer so easily as short ships, and it will not do for them to broach to, or to be pooped, in a heavy sea-way.

In all cases the designer has a right to claim the fullest information, not only in general, but also in detail, of the points which his design should fulfil. The absurdity of supposing that he can meet an unknown requirement is sufficiently exposed by being named.

In the merchant service these necessities are sufficiently met by the experience and theoretical knowledge which are already in the possession of the leaders of our profession. In the War Navy the requirements are far more complicated and precise, but far less definitely specified to the Naval Architect. There are, moreover, many traditions of the Navy, taken from the practice of sailing ships, which must be laid aside before it is possible to make a proper use of steam power.

I do not propose to enter into any lengthened criticism of our existing fleet. It is necessary to remark, however, that it is sadly deficient in sail power, and by no means strong in steam power. It cannot manœuvre under sail, and it can beat only to *leeward*. Over-sparred for steam, under-sparred and over-hulled for sailing, it performs both functions imperfectly, and that is no compensation for not doing one thing well. The ships are also very much over-manned in proportion to their number of guns.

It is idle to talk of good naval design so long as a topman is

looked upon as the ideal of a sailor, and cruising as the duty of the fleet. The sailor we now want should be boatman, gunner, and stoker, rather than reefer. A steam fleet should be either at anchor or at half boiler power, except when it is under full steam. Nothing can be more dangerous than the attempt to manœuvre a fleet in narrow waters and strong tides at low speed. We have it on the highest authority that the manœuvres in the course of which the Agincourt took the ground off Gibraltar were ill-devised and ill-executed. It is worth while to consider whether their chief defect was not the attempt to secure economy of fuel by means of low speed.

Moreover, no ship can be properly designed unless the guns of which it is to be the floating carriage, and the work which it is expected to perform, be settled and specified. When guns were small—six or twelve pounders—it was easy to build a ship fit for either, and then to arm her as thought best, although this did not always prove successful in the old wars. General strength would support small artillery. But you might as well try to mount a thirty-two pounder on a slated house-roof as to put thirty-ton guns in the strongest ship that can be built, without specially designing for those particular pieces. A very small margin of variation is all that can be reasonably provided for.

Underlying all this, however, is the question of the general defence of the Empire. Until a matured scheme for this has been made known to him, the designer must labour in the dark, and work perforce without a settled plan. Are we to sweep the seas, and show front at all points, as we did in the wars of the first French Empire? Or are we to do as we did in the early days of the French Revolution—hold securely some strong and well-selected places, on which we could fall back for supplies, and from which we could issue forth to smite the enemy at every open point? When the Naval Architect has made himself acquainted with this general plan—a plan which doubtless exists somewhere—when he knows the distances between his coaling, victualling, and repairing stations, and the accommodation to be expected at each—then, and not till then, he can usefully set about the design of a Navy. Scattered as our empire is, he must expect to have long distances between each station. Malta, the Cape, India, Sydney or Melbourne, Vancouver, the Falklands, some West Indian port, perhaps also the Bermudas, and Quebec or Halifax—these are

all the places in which he could have the means of docking and refitting large steam fleets, or in which he could reasonably expect to find heavy guns, spare screw shafts and propellers, or large reserves of sea-stores and coals. In time of peace, or in war with small Powers, he may expect to coal at small stations; but in serious war he must expect to find that great reserves, such as fifty or a hundred thousand tons of coal, and the means of docking and refitting, can only be placed at the few points for which strong garrisons can be spared, so that they must be separated by 5,000 or 7,000 miles of sea. If it is intended to blockade a coast, the first step is to seize some island or peninsula, and establish a dépôt. But this is independent of that general scheme for the defence of the Empire which is necessary to the design of our fleet.

Although advocating, as I have done, the use of full steam power, I do not mean to propose that ships should be altogether without sails. My belief is that steamships should have a fore-and-aft schooner rig, which could be sent down altogether if needed. Increased expenditure of coal will be necessary. I wish to record my opinion that this cannot be avoided if the Navy is to be made efficient. The true sources of economy are to be found in the improvement of the machinery and in the reduction of the crews. The establishments of sea-going ships are now settled mainly with reference to their sails. In full-powered steamships they should be settled with reference to the number of guns and the indicated horse-power. Thirty-five men per heavy gun (of 30 or 35 tons), and, in addition, one man per fifty I.H.P., would, in my opinion, be a sufficient complement in ordinary cases.

An interesting problem to the rising Naval Architect is the arrangement of the steam power auxiliary to the working of the ship. At present donkey-engines for each special work are stowed (without much system) in any convenient corner of the decks. What is needed is, that a careful and complete scheme should be worked out, dealing with the auxiliary steam service as a complete whole, entering into the general design of the ship, in the same way that the rig and the gunnery are now treated.

Ships for coast defence also present a very interesting problem, of which the present solution, in the slow monitor type, is a very defective one. The real data of the problem are as follows:—A

seagoing vessel of war, in addition to her means of offence and defence, is burdened with the condition of carrying coals and stores for a long voyage. From this condition the coast-defence ship is free. The true problem is, therefore, to utilise the reduction of the coals and stores, in providing greater speed or more formidable armament. Floating batteries may be cheap; but unless they have high speed they will be fit for the defence of ports or creeks, not for the protection of coasts.

For the attack or worrying of coasts, the chief thing in which we seem to be deficient is the adoption of a boat-gun of very long range, the effect of which would be to make it unsafe for the land power to establish either reserves or magazines within this long range of any creek which a boat could penetrate. Boat attacks can never be of real power, unless in support of military action; but their incessant worry may either occupy a large hostile force, or, if that be reduced, facilitate military attack and operation. Small draught of water and high speed are the essential conditions of efficient coast warfare.

The task I had set myself in writing this article was to bring into strong relief the following points :—

That the first condition of all successful design is that the requirements and purposes of the structure should be fully understood, both in general outline and in detail.

That for war-ships the general plan of naval defence or attack must be devised, and communicated to the naval designer, before he is set to work.

That the free use of high steam power, and the abandonment of sail power, except as a mere auxiliary to steam, is the immediate future of our Royal Navy.

That the ships' companies must be largely reduced, and that a careful arrangement of auxiliary steam power for the donkey-work must form a part of the design of the ship.

To develop these fully, and to justify them, would exceed the limits of space at my disposal. It is sufficient here to have stated them for the careful consideration of my readers, and especially of my old pupils.

ENGLISH NAVAL POLICY.

By Nathaniel Barnaby, Member of Council of the Institution of Naval Architects.

The supremacy of England on the seas has been not only the aim but the boast of successive generations of Britons. This aim has been regarded by her enemies, and by many of her friends too, as presumptuous and arrogant, but the boast has never yet been shown to be vain. It is not the purpose of this paper to justify the boasting, but to consider the aim, as to how far it is applicable to modern civilisation, and to what extent and in what manner it should influence the present naval policy of the Empire.

The necessity for this supremacy is partly due to our geographical position. The successive conquests of the island by Romans and by Northmen, who had the command of the seas, show that our encompassing waters gave special facilities for choosing the time and point of attack, and that without floating defences the sea was not a bulwark, but a levelled road easily traversed by the enemy, while it was useless to ourselves. And what was true when Romans, Danes, Saxons, and Normans successively ravaged the island is still true, for although coast fortifications have been multiplied, and the mobility of defending armies vastly increased, there has been a corresponding increase in the security and rapidity of the means of naval transit from the coasts of the enemy to our own. If, therefore, the interests of the island could be regarded as self-contained, and in no degree dependent on the permanence of the connection with other parts of the world, the preservation of the national institutions, and of the national life itself, would still require that the nation should possess floating defences capable of preventing the transport of a hostile force to its shores.

But the supposition made fails altogether to represent the magnitude of the real facts. These little islands in the North Seas are no longer the body of the Empire. They represent still,

perhaps, the head and trunk; but the blood of the nation pulsates across the oceans, and unites the head and trunk with the members of the body in America, Australia, and on the great continent of Asia. The volume and force of this vital current is enormous. It is represented by over seven millions of tons of British merchant shipping, worked by nearly three hundred and thirty thousand men. The value of this shipping alone, the mere carriers of the sea, would not be less than one hundred and seventy millions sterling. The value of the merchandise borne into and out of our home ports in one year, exclusive of foreign merchandise transhipped at ports in the United Kingdom, and of bullion and specie, amounted, in 1867, to over five hundred millions sterling, and increases annually by about fifteen millions.

If England were deprived of the power of guarding the courses of this vast current of life, or the circulation became suspended for even a brief period, such a disaster would probably lead to her dismemberment as an Empire, and leave her dependent on the forbearance and charity of her neighbours for her very existence as a nation.

It may be said that if the maintenance of the Empire and the preservation of the national independence involve the existence of a gigantic fleet of war ships, and keep alive bitter martial rivalries in Christendom, then it is inexpedient that the Empire should be maintained; that commerce would flow on still although the direction of the currents might be altered; and that the well-being of the vast populations of the world, of all kindreds and tongues, should be of more importance to an enlightened Englishman than the preservation of an Empire bearing his name, however gratifying the existence and traditions of such an Empire might be to his national feelings.

But even on this high ground, where patriotic feeling is displaced by Christian philanthropy, we may contend fearlessly for the maintenance of the Empire, and of its warlike maritime supremacy. It is undoubtedly a great misfortune that with so few Maritime Powers as there are, each one should have to go about his lawful business armed to the teeth for fear of the others; and when it is remembered that these Powers are almost without exception Christian, the state of things may be justly said to be scandalous. Russia, Sweden, Denmark, Germany, Holland, Belgium, France, Spain, Portugal, England, and the American Powers—all

of them are Christian. Yet one has only to look at their names in order to see the enormous difficulties which would require to be overcome before these nations would consent to disarm on the seas, and trust their maritime interests to an international police.

But while such an international arrangement can only be regarded as a pleasant dream, a very close approximation to its realisation is attainable, and lies within our own hands. A maritime confederacy of the English-speaking people would be almost as effectual in preventing panics, and protecting the highways of the sea, as an universal confederacy would be, and such an arrangement, depending only upon Great Britain and the United States of America, may be regarded as perfectly attainable.

But, coming still lower, the British Empire is itself already such a confederacy. Great Britain, British North America, India, and Australasia, with splendid harbours, with thousands of miles of seaboard for training seamen, and with vast populations depending on maritime trade—these Powers are so deeply interested in the preservation of maritime peace, that the strength and efficiency of their confederated navies would be in itself a guarantee for peace from a very large proportion of the wayfarers on the seas.

To speak of the British Navy as a confederated Navy is, perhaps, a somewhat bold figure of speech, but this is the true idea of the British Imperial Fleet. If a war were to break out, every part of the Empire would expect to be protected against the most powerful ships of the enemy. India has two small ironclads, and Australia one. What could these do for the defence of these valuable parts of the Empire? Canada has none, and New Zealand none; they are completely dependent on the Home fleet. In all these cases it is to be feared that the outbreak of a war would cause demands for ships to be made on the Home Government which it could not meet, and the result would be discontent and perhaps eventual severance from the Empire.

The true principle seems to be, not that this colony or the other should decide for itself whether it should have any floating defences of its own, of what description they should be, and how they should be employed, as is the case now, but that each part of the Empire should contribute towards the national fleet in proportion to the value of their exports, or on some other equitable basis. That each should have a certain fixed proportion of coast defence ships, and of vessels for the protection of the

lines of commerce. The former to be under the absolute control of the Local Government, and the latter under the control of the Imperial Government, which would be in communication with them all by the oceanic lines of telegraph, and could concentrate them on any point desired. The ordinary stations of the seagoing portions of the colonial contingents would be the Colonies themselves, and they would be manned and officered as far as possible by the Colonists, all of them being under allegiance to the Queen, and subject to the Imperial Martial Law.

In making this sketch it has been necessary to step beyond the province of the Naval Architect, for it is clearly impossible to forecast the policy of the English Navy, and foresee the character of its ships of war, except for the immediate future, without entering upon some such consideration as that given.

Such a Navy as that imagined would consist of three great divisions—coast defence vessels; ships capable of taking part in an engagement with a fleet which would otherwise blockade a harbour, or bar an important line of traffic; and lastly, vessels capable of keeping the seas for long periods, of engaging privateers, and making reprisals on the merchant ships of an enemy.

The first class—those for coast defence—should be capable of being worked by the seafaring population of the ports to be defended, in conjunction with the local steam shipping. The second class need not be cruising ships, but may have everything thrown into efficiency under steam in battle. The third class must be fast-cruising ships, economical in fuel and in men. All of them must be designed to suit local peculiarities of climate and of seaboard, and the furnaces should all be adapted to burn local fuel, so that we may no longer have to send English coal to Canada and India. It would doubtless follow from such an arrangement as has been considered that Canada, India, Australia, and New Zealand would all desire to undertake the creation and maintenance of their own portion of the fleet, under the control of the Imperial Government. English Naval Architects and Engineers would thus find an ever-widening field for the exertion of all their energies, and they would have the satisfaction of feeling that while they were creating the most formidable machinery of war, they would be the true pioneers of universal and enduring peace upon the broad seas.

ARMOUR FASTENINGS FOR IRON-CLAD SHIPS.

The question of armour fastenings having, during the present year (1871), been again revived, and grave charges brought against the Admiralty and others who persist in the adoption of the common or minus-threaded bolts, we propose to lay before our readers a few facts in connection with this subject, showing why the Admiralty continues the use of this form of bolt for armour-clad ships in preference to the plus-threaded, and we are the more anxious to do so on account of the vague notions which certain writers in our public journals seem to have with reference to this matter.

Armour fastenings have already provoked a great deal of discussion, owing to the different opinions held by those who have taken any prominent part in the construction of our iron-clad ships and land fortifications. But when two great departments of the State agree to differ, and each deliberately decides to adopt its own peculiar views, and that, too, after a costly series of experiments has been made to settle disputed points, it is no marvel that the public should express their dissatisfaction at this apparently anomalous procedure; and the case becomes all the more aggravated when the merits of the plus-threaded system are paraded in the newspapers with a plausible claim to superiority, and the minus-threaded bolt is represented as being *minus* of every good quality.

We read an article in one of our daily newspapers a short time ago, censuring the Admiralty in no measured terms for what was termed its persistent folly in not abandoning its system of armour fastenings and adopting the plus-threads. Now we must beg to differ altogether from the advocates of such views, for, in our opinion, the folly would be in acting upon their suggestions. This we hope presently to show would be the case both as concerns economy and efficiency. Does it follow, because the War Department has thought proper to sanction the use of these particular bolts for land fortifications,

that therefore the Admiralty must do the same for armour-clad ships? It may just as well be argued that animals which have been formed by the Creator to dwell on dry land, could live equally well in the sea if they would only try, as to suppose that the same description of work can be made to answer alike in both cases.

Armour-clad ships, we need scarcely say, have to carry and fight their guns, and must be constructed so as to be impervious to water as well as impregnable to shot, an achievement not very easily accomplished. The difficulty, for instance, of keeping these ponderous ships water-tight will be the more apparent if we consider how they are tossed upon the billows, and plunged into the hollow of the waves. The wonder is that they keep so free from leakage as they do, but this can only be effected by good, sound work, which we are glad to say the Admiralty always insists on. We may mention, as an instance of the great force with which water impinges against the bows of a ship, that in one of our earliest iron-clads, during her trial at sea, the manger scuppers, of lead $\frac{3}{8}''$ thick, collapsed, owing to the water forcing its way through the joint made with the scupper and wood fillings. The water pressing or impinging against the sides of our ships with such force renders it necessary, therefore, that the greatest care should be taken with the fastenings, and bolt-holes have to be caulked round the inside between the joints of the skin and wood backing, and a hempen grummet placed under the washer to prevent leakage. Yet, notwithstanding these precautions, the water sometimes forces its way through.

Before proceeding with the more technical part of our subject, let us define the terms we have applied to these bolts. Suppose, then, a screw-bolt to be made in the ordinary manner, the threads being cut on the points, as is usual for a common bolt, the diameter of the bolt, measured at the smallest part of the screw, will of course be less than the diameter of the shank. This, then, is what is meant by the term *minus* threads. Now, if we put this same bolt into the lathe and turn down its shank between the head and screw point until it is reduced in diameter to the smallest section of the screw point, or a trifle below it, we shall have the *plus* threads. In other words, the screw thread will be in relief upon the shank, and consequently the

point will be larger than the shank by the depth of the screw thread.

There is nothing novel in this description of screw thread, for it has been used for certain works from time immemorial; but the application of the principle to armour-bolts is, we believe, modern, and is patented by Major Palliser, who, some years ago, when armour-plating was in its infancy, witnessed, in common with others, a series of experiments at Shoeburyness with the armour-plated targets, representing both the sides of our iron-clad ships and our land fortifications. Seeing how destructive the firing at these targets proved to the armour-bolts, he immediately turned his attention to remedying this defect, which he endeavoured to do by changing the form of the bolts then in use, making them with plus in lieu of minus threads, and at the same time using a more costly and ductile quality of iron, with a view to resist impulsive strains. Others attempted to attain the same result by the introduction of elastic washers placed under the nuts, so as to deaden vibration and allow the bolt to yield at the moment of impact by shot. Various contrivances for these washers were resorted to, both with regard to the form and also the material, and at length the elastic cup washer was proposed and adopted for armour-clad ships, while the plus-threaded bolts were adopted for land fortifications. Both systems, it will be observed, aim at relieving the bolts from strains of enormous magnitude suddenly applied. In the one case the object is attained by the application of an elastic substance, placed, as we have said, under the nuts, and in the other by the stretching of the bolts themselves.

The elastic cup washer is fully described and illustrated in *Shipbuilding in Iron and Steel*, by Mr. E. J. Reed, C.B. A brief description of it here may, however, be of advantage. It consists of three articles—viz., a wrought-iron cup, having a flat surface to fit against the skin plating, an indiarubber washer which is placed inside the cup, and a covering plate or common washer. These have each a hole through their centres of the size to suit the diameter of the bolt to which they are to be applied. They are then threaded on to the point of the bolt in the order stated, the plate-washer or covering plate forming a base against which the face of the nut fits when screwed on. The proportions of these articles must depend upon the size of bolt and thickness of

armour plate. By this arrangement a kind of buffer is formed; but as indiarubber while being very elastic is practically an incompressible substance, care must be taken to allow sufficient room around the edge of the covering plate, so that when the bolt is overstrained by concussion, the indiarubber may be allowed to exude. The space around the edge of the plate referred to must be regulated by the texture of the indiarubber, and this last-mentioned quality must depend upon the size of the armour bolt. The form of these washers is hexagonal. This is for the purpose of preventing the indiarubber from twisting when a heavy strain is put upon it by screwing up the nut. They may be of cylindrical shape, provided the covering plate can be so fitted as to prevent its rotating while the nuts are being screwed up. The cup is intended to be a repository of latent elasticity, which will allow the bolts to yield at the moment of impact by shot at every round until the whole of the indiarubber has been squeezed out of the cups, just on the same principle as the stretching bolt which stretches until it breaks. So far, then, as yielding is concerned, the two systems may be said to be identical.

It must further be remarked with respect to the plus-threaded bolts, that Major Palliser, subsequently to the time we have referred to, added two other features to his system—viz., extremely fine threads, and a new method of forming the conical heads, concerning which he laid down a rule that they should not be made by *upsetting* the iron as is commonly done by smiths when employed on this description of work; so to carry out this idea, the bolt staves have to be provided large enough for the required diameter of the conical head. The iron is then "swaged" down from this larger diameter to that required for the shank of the bolt, the head being, of course, formed by the same operation.

The bolts now being used by the War Department for land fortifications differ in form from those we have just described. For instance, nuts take the place of heads, and the bolts closely resemble those used by civil engineers and others for the tie-bolts of bridges, &c. The mode of manipulation is, however, very different in the two cases. Those for land fortifications are made from bolt stave of the diameter of the largest part of the screw threads, the shanks between the screw threads being

afterwards turned down to the smaller diameter; while the tie-bolts referred to are made by simply upsetting the iron in order to obtain the increased diameter for the raised or plus thread. This is a matter of great importance from an economical point of view, and we will therefore give a few particulars illustrative of the precautions taken to insure the desired quality in the bolts made for the War Department.

From each length of bolt stave—say from 15 to 18 feet—a test piece 2 feet long is cut and prepared. It is fixed in a vertical position under a steam hammer by an apparatus specially arranged for the purpose, and then drawn asunder lengthwise by repeated blows. There must be a certain percentage of reduction in the breaking section as compared with the original section of the test piece, in order that the stave from which it was cut may be accepted. Should this percentage not be obtained, the whole stave is rejected. Our readers will probably think this an extravagant and costly precaution, especially when compared with the Admiralty test of one bolt out of every hundred.

The latter test is also percussive, but is made by means of an article termed a "tup" (about 1 ton in weight), let fall through a space of 30 feet, the test bolt being so placed that the fall of the tup shall bring upon it strains similar to those caused in the fastenings by the impact of shot upon the armour plates on a ship's side. Of course, with the War Department's system of fastenings, great ductility is, as we have said, essential to the success of the bolts, and the elaborate tests described above are indispensable. But a quality of iron which would certainly fail to satisfy the War Department's requirements, and would break under trial because of its want of ductility, might with elastic cup washers answer every purpose. The difference in the cost of the iron would be considerable, as some of our readers will understand when we state that the quality now being used by the War Department, and manufactured by Sir John Brown and Co., costs 21*l.* per ton.

The nuts and washers for land fortifications are also of a novel pattern. They are made on the ball and socket principle, and are termed spherical nuts and coiled washers. The socket for the nut which answers for the head of the bolt is made in the armour plate itself by countersinking the plate to fit the spherical nut.

The washers at the points of the bolts are made up of two parts as follows:—A socket to receive the nut (circular in form) is first made out of coiled bar iron welded, of the required thickness. On the outside of this a screw thread is cut for the purpose of receiving a jacket or coil of bar iron, which is first put into shape by being bent hot to the form required, and when cold a screw thread is cut on the inside to coincide with that on the external part of the socket. This coil is not welded. The two are then screwed together, forming one washer, the coil on the outside acting as a supporter in order to prevent the socket from bursting at the moment of impact by shot, and at the same time giving elasticity to the nut. The nuts being thus made from coiled iron are expected to expand when concussion takes place, and so allow the nut to yield to the strain. It will therefore be observed that the materials of which these bolts and nuts are made must be of the very best description and of special manufacture. The washer is patented by Lieutenant English, R.E.

Shipbuilders will at once see from our description of these bolts that they are not at all adapted for iron-clad ships, in their original form, and that in order to render them suitable their shape must be changed, so that externally they may be of the same form as the minus-threaded bolts, by coating them with some metallic or other substance—that is to say, instead of their points being larger in diameter than their shanks, the order must be reversed, and the points must be the smaller. This is absolutely necessary to insure sound water-tight work, and in some of the earlier Palliser bolts the recessed part of the shank was filled up with an alloy of antimony and lead for this purpose, but the plan was afterwards abandoned. The additional expense (we were told at the time) for this extra work so increased the cost as to make them equal in value to their weight in silver. But this was, no doubt, an exaggerated statement.

We shall not stay here to discuss the merits of this combination of metals, further than to say that we should not like to answer for the consequences which would be likely to ensue when these metals are brought into contact with sea-water.

But let us now suppose that this plan can be carried out by the introduction of some metallic or other substance, and that the bolts having been driven tightly through their holes are water-tight. The ship goes into action. What follows?

According to the theory of the patentee, the first blow the armour plating receives, the bolts in the vicinity of the shot-hole, or indent, as the case may be, are to stretch, and as a necessary consequence there will also be a corresponding reduction in the diameter of the bolts so acted upon. These bolts of course are at once rendered slack in their holes, when leakage must ensue if the damage is in the neighbourhood of the water-line, and this at a time, above all others, when water-tightness should be preserved, and the guns, and not the pumps, well manned.

We may also mention another contingency which has to be studied, should this plan be carried out, and that is the probability of the nuts jarring off at the moment of impact by shot, owing to their not bearing evenly against the skin plating, on account of the difficulty of boring the holes exactly at right angles to the side of the ship. We know that the slightest deviation in this respect will cause a transverse strain to be brought upon them simultaneously with the tension, and the effect of this will be to fracture the bolt at the thread next to the skin plating, and so jar off the nuts. We do not say that this defect could not be obviated by using tapering washers, but even then there would be a degree of uncertainty about it, as the workmen themselves may be deceived in this manipulation, and the same evil would exist in the common bolts, were it not for the elastic cup washer, which acts as a regulator in this respect, for no sooner is a slight strain put upon the indiarubber which is confined within the cup, than a uniform bearing under the nuts is virtually obtained by the accommodating nature of this material.

The spherical nuts already mentioned were introduced, no doubt, partly to obviate the same evil, but then it must be borne in mind that the bolts used for land fortifications are all loose in their holes, which allows the nuts to accommodate themselves when a sudden tensile strain is brought upon them, and it is not too much to say that the success which has attended the trial of these bolts is in some measure due to this fact.

The benefit derived from the indiarubber has been fully verified by the experiments at Shoeburyness, and although the late trial with the 14-inch plated target was not so successful as could have been desired, this ought not to detract from the merits of former trials, but, on the contrary, should form a ground for inquiring why the bolts for thick plates cannot be

made to stand as well as those used for thinner ones. We are glad to find that this view of the case has been entertained by the Admiralty, and the partial failure referred to will no doubt be rectified in the ships themselves.

New systems of work, or reconstructions, as they may be termed, are seldom or ever developed all at once. Experiment after experiment has sometimes to be made before certain vital points can be satisfactorily determined. This is especially the case with regard to armour plating and fastenings. No sooner have the requirements in one case been fairly met, than the arrangements have to be altered to suit another where the parts are of larger dimensions and of different construction, owing to the guns gradually growing in weight and calibre. Consequently the professional officers who have to arrange the details of construction are continually having forced upon them a re-adjustment of the fastenings, involving the employment of bolts of larger diameter, stronger cups, and an increase in the thickness of indiarubber. These particulars have all to be decided, and this cannot be done correctly in the absence of experiments, owing to the amount of buckling these extra thick plates will undergo at the moment of impact by shot. This was evidently the case with the last experimental ship target tried at Shoeburyness. The firing at this target with the 25-ton gun was so terrific in its results, that the wrought-iron cups which contained the indiarubber were found to be too weak to withstand the violent concussion and sudden distortions of these extraordinarily thick plates, consequently the cups burst sideways, allowing the indiarubber to escape, thus bringing at once iron into contact with iron, and fracturing the bolts. But it is worthy of remark that the bolts all withstood the first round, although the cups burst.

It is impossible to anticipate the effects of the discharge of one of these heavy pieces of ordnance against an armour-plated target, and therefore it is not fair to expect that all the necessary details can be successfully arranged before some idea has been formed as to the requirements of the case. Nor have we yet learnt that these things are managed any better by the War Department, for if Shoeburyness could testify to anything at all, it would to the failure of the first trials with the Palliser bolts, notwithstanding all the pains that had been taken to insure success by previously testing the iron, and by all other

available means. But to revert to the use of elastic cup washers, we think it only fair, after what has been said on the other side of the question, to give some positive proof of their utility from actual experiments made at Shoeburyness, for Major Palliser himself did not appear to be in full possession of all the facts of the case when he read his paper on Armour Fastenings at the annual meeting of the Institution of Naval Architects, in 1867. Otherwise, we are at a loss to account for his statements, especially during the discussion which followed, for he then appeared not to be able to recollect anything good of these washers as compared with his own plan. For instance, when asked if the bolts he had been referring to had elastic cup washers, his reply was, that the "box-target" was fitted with them, and they were nearly all broken. Now, what is the history of this old target? We call it old, because in one sense it was never new, having been constructed entirely out of old materials, as the following statement will show:—

The Ordnance Select Committee, at the time we are referring to, having a number of projectiles to test, and being anxious to economise as much as possible, resolved to use up all the old materials then lying on the ground at Shoeburyness that were available for the purpose, consequently old bolts, old cups, and old indiarubber were among the things that were brought into requisition. The bolts and washers were the same as had been used at the trial of the *Bellerophon* target, and had done their work successfully, not one of the bolts with these washers applied to them having failed on that occasion. In order to render these very bolts available for the "box-target," not only had they to be repaired, but also lengthened. Hence it could not be expected that they should stand as well as new bolts and washers, and no one who had anything to do with the construction of this target ever dreamt that any notice would be taken of these fastenings. In fact, it was distinctly understood officially that the sole object of the erection of this target was the trial of projectiles. Let us, however, inquire what was the state of the target at the time referred to by Major Palliser?

When we last examined the structure to ascertain the amount of damage it had sustained after three days' firing from the Woolwich 7-inch rifled gun, at a range of 200 yards, we found it had received 22 rounds in a space 13'.6" × 8'.6", which were

the dimensions of the target proper. We need scarcely tell our readers that it was knocked nearly all to pieces, and the marvel was that any bolts should have been discovered unbroken. However, we could only find seven out of twenty that were *broken*.

Major Palliser also attributed the partial success of these washers to the very fine threads he had introduced on some of the experimental bolts. We, however, apprehend that he referred to an experiment that was made with cork washers against his system, when it was considered only fair that the bolts should have one uniform thread.

We shall presently have occasion to allude to these experiments. At present, however, we shall only say that the Admiralty does not recognise any other elastic cup washer than those with indiarubber, and up to the present time there has been no trial of these in competition with the Palliser bolts, nor has the Admiralty adopted the very fine threads.

When Major Palliser read his paper on armour fastenings, only two experimental trials with the elastic cup washers had been made under the direction of the Admiralty. The first took place with the *Bellerophon* target in February, 1864. One half of the bolts had common plate washers and double nuts, and the other half had the elastic cup washers and single nuts,* and the bolts were $2\frac{1}{2}''$ and $2\frac{3}{4}''$ diameter respectively, with about five threads to the inch. The result of one day's firing, which was all this target was subjected to, was the breaking of two bolts with the common plate washers. None of those with elastic cup washers were injured. The comparative success of this trial with the bolts was attributed to the strength of the target not allowing the plates to buckle so much, and the bolts being comparatively of larger diameter.

The other experimental trial was a more important one. It took place on the 29th August and 14th September, 1866, with one of the *Warrior* targets, being the same in all respects as those previously fired at when the bolts so signally failed; as many as from 6 to 9 breaking in one round. There were 51

* It was the practice, before the introduction of elastic cup washers, to use lock nuts, owing to some of the single nuts flying off at the moment of impact by shot, but the spring in the cup-washer obviates the necessity for double or lock nuts, as it keeps the single nut tight on the bolt.

bolts in all driven in this target, 25 of which were fitted with elastic cup washers, and the same number with Paget's steel spring washers, the odd one having a common plate washer only. The result after two days' firing was as follows:—Eighteen bolts with steel spring washers were broken; the odd bolt having a plate washer was broken at the first round. Not one of the bolts fitted with elastic cup washers was broken.

With these facts before them, how could the Admiralty do otherwise than adopt their present system? Bolts with ordinary plate washers had utterly failed, and no other system of fastening had proved so successful as the elastic cup washers.

The success of the above trial was considered all the more conclusive on account of the bolts having been driven into and out of another *Warrior* target, a fac-simile of the one we have just described, the elastic cup washers having been under heavy pressure for 22 months at Shoeburyness, exposed to all sorts of weather. This circumstance occurred through the Ordnance Select Committee at that time determining that three other systems of fastenings should take precedence of trial, there being no other target available. These we may mention were Palliser's, Head and Ashby's wire bolts, and the common ones with Clarkson's cork washers fitted to them; some of the latter having iron cups similar to those used for indiarubber. These three sets of bolts had very fine threads, as many as 16 to the inch, and so delicate were they, that it was with great difficulty the bolts could be driven without injuring them. The result of this trial proved that the Palliser bolts and those fitted with cork washers were about equal as regards efficiency, while Head and Ashby's wire bolts signally failed. Clarkson's cork washers were found, however, not to answer the same purpose as indiarubber; there being comparately no lateral extension with this material, iron cups were therefore not needed. In addition to this, the cork became as hard as wood, by simply screwing up the nuts. No doubt the very fine screw threads, together with a more ductile and costly iron, considerably improved the bolts.

We are not in possession of the details of these three experiments, and therefore we cannot say whether any of these fine screw threads stripped during the firing. We merely advert to the trial of these bolts on account of its historical connection with the one just described.

We have hitherto confined our remarks on the Palliser bolts to their applicability to ships' sides; but as we wish to give an unbiassed opinion upon the whole question, let us consider lastly the advisability of adopting them in turrets where water-tightness is not so important. It will, therefore, be necessary for us to inquire what thickness of wood backing will have to be provided for, and here we may at once say, that if the same arrangement as that now adopted for the *Cyclops* class of turret ship should be proposed as the one to carry out this particular system of fastenings, it will be impracticable, for we do not suppose that the country would like rickety turrets any more than they appear to like rolling ships. But with a backing similar to that of the *Warrior*, of, say, 18ins. thick, it might be arranged thus by allowing the bolts to have a length of 6ins. for stretching in the middle of their shanks, with the same length of hold in the wood backing at each end. The form of bolt in this case, however, would have to be modified in order to reduce their points for driving.* A drift of $\frac{1}{4}''$ for a 3-inch bolt is generally allowed to insure tightness.

In the latest turret ships the armour is, we believe, to be arranged in two thicknesses, with a layer of wood backing between them, and a second layer of wood between the inner armour plates and the skin plating. In wake of the inner armour the shanks of the through bolts are to be reduced to give spaces for stretching; but they will maintain their full size through the outer armour, and both thicknesses of backing. The use of elastic cup washers will be continued, and thus the two systems of fastenings will, to some extent, be combined.

W. B. B.

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* Three other methods are given by Mr. Reed in his work on Shipbuilding in Iron and Steel as substitutes for the Palliser bolts, with a view to overcome this difficulty, but only one of them has yet been tried—viz., that proposed by Mr. Parsons and adopted in the Millwall Shield, which was tested at Shoeburyness some time ago; but as the bolts were all fitted with the elastic cup washer, the success which attended them could not with fairness be ascribed to the plan.

ON TESTING THE VALUE OF UNGUENTS.

In this article it is intended to consider merely the unguents used for machinery, and therefore to confine the attention principally to those qualities which are essential for this purpose.

In testing unguents with a view of ascertaining both their absolute and relative values, it is necessary to fully bear in mind what an unguent really is, the use for which it is employed, and the particular qualities we should especially look for in it. First then, an unguent is some substance a thin film of which is capable of preventing the surfaces of two parts of a machine (working together) from coming into actual contact; next, the use of an unguent is to reduce the resistance due to friction—that is, with an unguent the friction should be less than what it would be were the two surfaces actually working in contact, and of course with the reduction of friction there will be a reduction of the wear and tear of the working parts; another use of an unguent is to assist in conducting away the heat which has been generated by the friction.

The quality of an unguent will depend in a great measure on the fulfilment of the above conditions. That is to say, the substance should possess sufficient viscidity to prevent the film being forced out by the pressure with which the two surfaces are kept together; and not enough viscidity to make the friction either equal to, or greater than, that caused by the surfaces themselves rubbing together. The substance, also, by its flowing away, should be able to take away the heat generated by the friction, and so prevent the temperature of the working parts being increased to an objectionable degree. To accomplish this last it must have sufficient fluidity to flow constantly, though slowly, through the bearings, &c., and also to remove any of the solid matter left on the decomposition or evaporation of any part of the unguent.

There are also other properties of unguents which will affect their quality and relative value—namely, their action, if any, on the material of which the surfaces are composed; the action of

the atmosphere on them; and the facility with which they can be used in the instruments, or other means, employed for lubrication.

Another point to be borne in mind is the special purpose for which the unguent is to be employed: for example, a lubricant must generally be obtained which is adapted to the pressure by which the rubbing surfaces are kept together, as under a certain pressure (per unit of surface) the minimum friction will be given with one lubricant, and under another pressure with some other lubricant. In some cases an unguent must be provided suitable for the speed at which the machinery moves, as it has been found that a lubricant which will reduce the friction to a minimum at one speed will not so reduce it at another speed. Again, an unguent must sometimes be chosen to suit the material of which the surfaces are composed; for though, as a rule, the friction of two surfaces rubbing together depends on the unguent, and not on the nature of the material, still, in some cases, it is found that some particular lubricant is more suitable for certain surfaces than any other.

Of the substances fulfilling the conditions above specified, most belong to a class of bodies known as fats or oils, a large number of which are found to possess all the requisite qualities, in a greater or less degree, though some few other substances, such as water, graphite, &c., are occasionally used. These various bodies will, of course, vary in point of importance according to the special purpose for which each is to be employed.

The fats or oils used for lubrication are principally animal fats and vegetable fixed oils. Animal fats, though at ordinary temperature more or less solid, may be regarded, both on account of their general properties and chemical constitution, as varieties of oil, and we shall therefore include them under the general term of solid oils; there are also animal *oils*, properly so called, as whale oil (commonly called train oil), spermaceti oil, &c. Most animal oils, being of a nature known as fixed oils, may be used for purposes of lubrication; but being generally solid at ordinary temperatures, they are principally employed for lubricating those parts of machines which work at high temperatures, which high temperature is not due to friction, but to some other cause; sometimes to the agent by which the machine works, as, for instance, such parts of the steam-engine as the cylinder and slide-valve. The most common of the animal oils are:—Tallow, the

fat of sheep, oxen, and deer; lard, the fat of hogs; seal oil; whale oil; and spermaceti oil. Vegetable oils are very numerous, and most of them are fluid at the usual temperature, but very few can be used as lubricants, as it is necessary that oils so employed should be only those known as fixed oils, and they must be non-drying as well; the chief of these are olive oil, rape oil, almond oil, colza oil, cocoa-nut oil, and palm oil (the last two oils are soft solids at ordinary temperatures). The oils that are liquid at the usual temperature are used for machinery in general, where the working parts are to be kept at a low temperature, and when, of course, the employment of solid oils would be inadmissible. Mineral oils also are sometimes used as unguents.

In some few cases other bodies are used as lubricants instead of oils; for example, water has been found to answer the purpose, where metal and wood, or metal and leather, are working together; and graphite and steatite (the substance known as French chalk) have been lately used as the lubricating matter in steam packing. We may mention, in passing, that soapy unguents (composed of an oil, an alkali, and water) are used for temporary purposes; but as they are not generally used for machinery, we need not again refer to them.

Having briefly noticed the several points to which we must turn our attention with reference to unguents, their properties and qualities, we may now proceed to detail the observations which should be made on, and the means which may be employed for testing, these various substances, with a view of ascertaining their values as lubricants.

Two sets of observations may be taken—viz., one on the nature and properties of the oil without the aid of machinery; and the second on the properties and qualities of the oil when practically used on machines. The first set will include the following observations:—The limit of temperature at which the oil ceases to be liquid, the effect of the atmosphere on an exposed thin film of the oil, the effect of the atmosphere on the oil in tanks or cans, and the effect of the oil on iron, brass, &c.; the question of *cost* might also be included under this head, but the consideration of this question must not be separated from the practical value. The second class of tests on the practical use of the oil in machinery should include: the manner in which the surfaces are working together, and the

circumstances, in every detail, under which the parts are working; the quantity of oil used in a given time; the friction of the parts while in motion, or the *friction of motion;* and the friction of the parts when commencing to move, or the *friction of rest.*

Now to return to the first series of tests. We have first to note the temperature at which the oil ceases to be liquid, for it is requisite that the oil shall be in this condition at the temperature at which the machinery usually works, and, for machines in general, that will be the ordinary temperature of the atmosphere, for if the oil be not liquid, it is evident that the heat which is required, first to raise its temperature to the melting point, and afterwards to liquefy it, must be generated by the friction; and this heat will be in addition to that usually and unavoidably produced by friction when a liquid oil is used. This additional amount of heat represents, and is equivalent to, so much extra work to be expended in friction, for the useless purpose, so far as the efficiency of the machine is concerned, of melting the lubricant.

Next, with regard to the effect of the atmosphere on an exposed thin film of the oil. It has been previously stated that none but fixed and non-drying oils are used as unguents. By a fixed oil is meant one which is not volatile, or which cannot be obtained by the process of distillation; and by a non-drying oil, one which does not absorb oxygen, and so become hardened, is not liable to volatilisation, and of which the more liquid portions do not, as in some oils, decompose and leave the more solid behind. It is evident, therefore, that if an oil were a perfectly fixed oil, and also perfectly non-drying, the atmosphere would have no effect upon it at all; but we know that *no* oil possesses these properties perfectly, from the fact that every oil has some peculiar odour, which proves that some part (probably an exceedingly minute quantity) of it evaporates, and that most oils, known as non-drying, on being exposed to the air for some time, eventually become dry. Therefore, what has really to be observed is the relative degree that oils fall short of being perfectly fixed and non-drying oils.* In making these observations, care should be

* Oils in the process of drying become, first, of the consistency of liquid varnish or gum; and should any oil, after exposure for a moderate time, be found to become adhesive, it is useless as an unguent.

taken that the oils do not gather dust from the atmosphere, and so interfere with the correctness of the results.

The next point is the effect of the atmosphere on oils in tanks or cans. Of course the same effect will be produced as in the case of oils exposed in thin films, only that it will take a very much longer time; it is, therefore, simply a question as to how long the oil will retain its original properties. Again, it has been found that the oils which retain their fluid condition at low temperatures, when kept at a low temperature (near the freezing point of water, according to the description of oil), deposit a substance known as *stearin* or *margarin*, the two principles of which oil consists—viz., *olein*, the more liquid portion, and *stearin* or *margarin*, the more solid portion—becoming separated.

We have now to consider the effect of oils on iron, brass, &c., when in contact with these metals. Oils may act chemically on metals, either by their decomposition, when the metal will combine with one or more of the constituents of the oil then set free, or by having acid properties which will act directly on the metal. The action of an oil on copper or brass may be taken as an example of the former, and the action of certain oils on iron as an example of the latter, for when certain oils are used to protect iron from a moist atmosphere, to prevent oxidation, it has been found that they produce a chemical action on that metal, which is due to the acid properties they possess; but the greatest evil is brought about by the acid properties in oils, when, with iron and brass or copper in contact, a galvanic action is set up.

With the best oils very little effect is produced on the metals of which the working parts of machines are composed; therefore, if, after keeping any oils in contact with these metals for some considerable time, any decided action is noticed, such oils should be rejected for lubricants.

We will now proceed to the consideration of the second series of observations, the object of which is to ascertain the more immediate qualities of oils in their practical employment as lubricants. The first point which should be noted is the special purpose for which the lubricant is to be used—that is, the manner in which the parts of a machine are rubbing together; for instance, one part may be revolving within another with a motion either continuous or alternate in direction; or one part

may be sliding within the other; or, again, the rubbing parts may be plane surfaces. There are other ways in which parts of machinery may work together, but the above are the principal.

Then the circumstances under which the rubbing surfaces are working should be noted—namely, the pressure with which the surfaces are kept together; whether that pressure is uniform, as in ordinary shafting, or whether it is variable, as in cross-head guides, &c.; or if the pressure is suddenly applied at intervals, as in the bearings of a connecting-rod. Next, the speed at which the parts are moving should be observed: whether the speed is uniform or variable; whether the machine has intervals of rest; and with regard to plane surfaces working together, whether these are horizontal, vertical, or inclined.

Such observations as these, combined with those we shall mention presently, may be noted so as to ascertain whether a particular oil is adapted to a particular kind of machinery.

With regard to the remaining tests which have to be made—viz., the quantity of oil used in a given time, the friction of motion, and the friction of rest—there have been machines made for the special purpose of accurately ascertaining these points. These machines are usually called oil-testing machines; the working parts with which the oil is tried are generally a bearing of some sort, with a shaft or drum revolving within it, so that the manner in which one part is rubbing on the other cannot be varied. In some machines, however, experiments may be made with various speeds, and under different pressures keeping the surfaces together, and also with a variety of materials in the surfaces themselves. The testing is carried on as follows:—A thermometer is fixed to the bearing in such a manner that the temperature of the rubbing parts is obtained as nearly as possible. The lubricator is so constructed that the quantity of oil which flows into the bearing may be easily measured, means being taken also to vary the quantity supplied if necessary. To measure the friction, the whole or part of the bearing which is experimented on is free to revolve (within certain limits) with the shaft. It is carefully adjusted so as to be in equilibrium when the shaft is at rest, and when the shaft is revolving the friction will, of course, have a tendency to move the bearing round with the shaft, but this tendency to move is counteracted and the friction measured by a weight on the bearing acting in the opposite direction. This

weight is made capable of being moved towards or from the centre of the shaft, so as to accurately balance the friction, and therefore measure force due to friction with the greatest nicety. Both the *friction of motion* and the *friction of rest* can be ascertained by this means. The results obtained from an oil-testing machine of proper construction are reliable, and therefore very valuable, although it must be borne in mind that these results are obtained only for a shaft revolving in a bearing; still, at the same time we must not forget that a large proportion of the working parts of most machinery consists of revolving shafts. However, if it is required to make further observations with parts working with different motions, or if trials have to be made where an oil-testing machine is not attainable, recourse may be had to machinery in general.

In trying oils on machinery in general we must first select certain bearings, or other working parts on which to make the experiments. The experiments may then be conducted in two ways: first, just sufficient oil should be used to prevent, if possible, the temperature of the working parts from rising too high, and the quantity should be accurately and periodically noted; the temperature also of the rubbing surfaces should be recorded at regular intervals; for the rise of temperature due to friction will be nearly proportional to the friction itself, and where the absolute friction cannot be measured, as is done by an oil-testing machine, the rise of temperature will be sufficiently approximate to show the relative values of the friction with the use of the various oils on trial. Secondly, the experiment may be conducted in this way: let a constant minimum quantity of each oil under trial be used in a unit of time, in turn on the same working parts, and note the rise of temperature in a certain interval of time in each case; for it has been already stated the rise of temperature will be *nearly* proportional to the friction. We say *nearly*, for although the heat given out by friction is exactly a *measure* of the friction itself, the temperature is not quite a measure of the heat. A more extensive and thorough practical trial of oils might be made in factories, with large engines, &c., where it is proposed to use any of them for machinery generally in this way. Let each oil to be tried be used in lubricating the entire plant of machinery for a definite period, noting the quantity used; and during that period take indicator diagrams of the

driving engine, as frequently as necessary, to obtain the average power developed; note also the consumption of coal, or, what would be more accurate, the quantity of water evaporated by the boiler. Care should be taken, too, that, as far as practicable, the amount of useful work done by the machinery should be exactly alike on all the trials, and this would be possible in many cases. Then, under such circumstances, the only work that will vary is that required to overcome the resistance due to friction, and the difference in the gross power developed by the driving engine will show the variation in the friction. One or two trials of about two or three months' duration, with each kind of oil, would be a fair practical test. In conducting these trials with oils, ample time should be given for making all observations as complete as possible.

Lastly, with regard to the money value of oils. The question of first cost of oils will always be considered as a very important one, especially in large establishments where an immense quantity is used; but at the same time due consideration must be paid to the quantity required, and to the friction of the machinery when using these oils, bearing in mind that increased friction means increased wear and tear of machinery, and an increase of power for driving; or, in other words, an increase in cost of repairs and consumption of fuel. For instance, take the case of olive oil; which, though somewhat expensive, has been found to possess all the qualities required of an unguent, and to answer admirably for nearly all the purposes of lubrication. Suppose we wish to compare with it a cheaper oil (care being taken that we have *pure* olive oil, for it is sometimes adulterated with poppy oil, which is a drying oil, like linseed); after a fair trial with both oils, we *may* find that against a supposed saving with the cheap oil we have to compare the following items:—a larger quantity of the cheaper oil consumed; additional outlay for repairs; a larger consumption of fuel, and perhaps also more labour to keep the machinery, &c., clean. And this greater expense in producing useful work may more than counterbalance the apparent saving in using the cheap oil, thus verifying the old proverb that "the dearest is sometimes the cheapest in the long run."

A. B.

ON THE FUNDAMENTAL PRINCIPLE OF THE ACTION OF A PROPELLER.

BY JAMES H. COTTERILL, M.A., VICE-PRINCIPAL OF THE SCHOOL.

THE action of a propeller would be a question of considerable interest considered simply as a problem in theoretical mechanics, and its important practical applications render some knowledge of it indispensable to the Naval Architect and marine engineer. No one can have attempted to design or improve a propeller without having in his mind some idea of the mode of operation of a propelling instrument, and of the conditions of maximum efficiency to which it is subject. Yet it is only within the last few years that such knowledge has assumed such a definite form, and been founded on such definite and widely-received principles, as to be entitled to the name and position of a theory. Even now the question is sometimes regarded as a very difficult one, incapable of treatment without a formidable array of mathematical symbols, so far as it is capable of treatment at all.

Unquestionably the problem has its difficulties, some of which have as yet been but imperfectly overcome, but we believe that the progress which has been made in its solution has been mainly due to the recognition of a principle in mechanics not more difficult to understand and apply than that principle familiarly known as the "Principle of Work," with which all engaged in practical work are so well acquainted. Inasmuch as M. Brin has recently called attention to the subject of propellers in a paper read at the last meeting of the Institution of Naval Architects, we have thought it might interest some readers of the *Annual* if we attempted to explain in a manner as far as possible divested of mathematical forms and unfamiliar expressions the principle alluded to, and to trace, as far as the limits of an article admit, its more important applications to the theory of propulsion. We shall do this by drawing a parallel between this principle and the principle of work, explaining step by step the analogies which exist between the two, and the differences which separate them, causing sometimes one and sometimes the

other to be the more convenient in application. To thoughtful students of the original papers* little that we say will be new, yet perhaps even such may not be sorry to see the question re-stated in a somewhat different form.

Elementary Principles.

To commence at the beginning, let us first take the case of a body moving from rest in a straight line under the action of a constant force in that line, then we know that if P be that force, v the velocity of the body at the end of time t,

$$P\,t = m\,v,$$

where m is a constant, called the "mass" of the body, depending, first, on the size, secondly, on the density of the body, while the product $m\,v$ is called the Momentum of the body. Thus the force multiplied by the *time during* which it acts is equal to the momentum of the body; and if the body have initially a given velocity, then we have only to substitute "change of momentum" for momentum.

But, further, we know that, if x be the space described, we have similarly

$$P\,x = \tfrac{1}{2}\,m\,v^2,$$

so that the force multiplied by the *space through* which it acts is equal to half the mass multiplied by the square of the velocity, or, as we commonly say, to half the vis viva of the body, while if the body have initially a given velocity, we say that the change in the half vis viva is equal to the above-mentioned product.

In the simple case, then, of a force acting on a body moving in its direction we see that the mechanical effect of a force may be measured in two ways: if it be considered as acting *through space* its measure is the change produced in the half vis viva of the body on which it acts, while if it be considered as acting *during time* its measure is the change in the Momentum of the body which has been produced in the time. And these two ways of measuring force are not independent but mutually convertible, the above equations being connected by the relation $x = \tfrac{1}{2}\,v\,t$—necessarily true whenever a point moves with uniformly increasing velocity quite irrespectively of any considera-

* We refer especially to the "Mechanical Action of Propellers," by Professor Rankine, and to "Apparent Negative Slip," by Mr. Froude, read before the Institution of Naval Architects in 1865 and 1867 respectively.

tion of the cause of that motion—by means of which either of these equations may be deduced from the other.

In modern scientific works, forces are measured by the velocities they generate in bodies of given mass, but in practice forces are measured by units of weight such as pounds, so that the product $P x$ to which the familiar name of "work" belongs is measured in foot-pounds or foot-tons. Hence the force P is said to accumulate in the body on which it acts $P x$ foot-pounds of mechanical work which is stored up in the form of vis viva and reproduced again whenever the body is reduced to rest.

Now we have no similar name for the product $P t$, but we see at once that it depends on *time* and force just as $P x$ depends on *space* and force; hence it is properly measured in second-pounds or second-tons, and we may now say that the force P accumulates $P t$ second-pounds of momentum in the body, all which must again be reproduced whenever the body is reduced to rest. If we had a name* for $P t$ the analogy would be perfect, and in fact the two cases are precisely parallel; for instance, just as we speak of $\frac{v^2}{2g}$ as the "height due to the velocity v," so we may with propriety—since $P t = W \frac{v}{g}$—call $\frac{v}{g}$ the time due to the velocity v. And this analogy suggests that if we dwell too exclusively on the *space-effect* of force we may overlook important results obtainable by considering the *time-effect* of force. Following out this idea, let us now generalise, commencing with the

PRINCIPLE OF WORK.

Let us suppose any number of particles connected together in any way and acted on by any forces acting in any directions, then the work done by those forces as the particles move from one set of positions to another is spent in two ways—(1) in changing the half vis viva of the particles, (2) in overcoming their mutual actions. The half vis viva of the particles is simply the sum of the products formed by multiplying the mass of each particle by

* Sir W. Thomson has called the $\int P dt$ "the time integral," but this name is not very suitable for our purpose. For want of a name we are frequently obliged to use the word "force" where we really mean the "time integral," or else to restrict ourselves to the change which occurs in a unit of time.

the half square of its velocity estimated *without reference to direction*, while the way in which work is spent in overcoming mutual actions is easily understood by imagining the particles connected by elastic strings, in which case it is plain that the work done in stretching the strings must be considered as part of the effect produced by the work done by the external forces. In two cases—namely, that of a rigid body and that of a perfect incompressible and frictionless fluid—this second part does not exist, and the work done by the external forces is equal to the change in the half vis viva. In an actual fluid the present state of our knowledge respecting molecular action hardly permits us to say whether the work dissipated in "friction and shock" should be placed wholly in the first or partly also in the second class; we only know that the work done by the external forces must be equal to the half vis viva due to *visible* motions together with the work dissipated as above. This is the principle of work as applied in hydrodynamics, a principle of wide and well-known application; there is, however, this obstacle to its use—namely, that the amount of work dissipated in friction and shock is usually large and difficult to estimate. Thus the greater part of a work on hydraulics is taken up with the discussion of the "loss of head" by resistances of various kinds, a loss about which little is known except through direct experiment. In the theory of propulsion this obstacle is so serious that little or no progress has been made with the question by aid of the principle of work alone. Let us, therefore, now try and generalise our other principle, which we may call the

PRINCIPLE OF MOMENTUM.

First suppose a particle moving in any way under the action of a force constant in magnitude and direction, then the ordinary laws of motion tell us that the change of momentum *in the direction of the force* is equal to the product of the force and the time—that is, momentum, instead of being estimated like vis viva, irrespectively of direction, must always be estimated in the direction of the force we are considering. Next imagine two particles A and B connected together in any way, and acted on by a pair of forces constant in magnitude and direction, then since "Action and Reaction are equal and opposite," with whatsoever force A draws B in any direction, B will draw A in exactly the opposite,

and hence it is easily conceived that whatever momentum the mutual action of the particles generates in A in any direction, it will generate an exactly equal amount in the opposite direction in B, so that, if we understand by the accumulated momentum in any direction the sum of the momenta of A and B when moving in the same sense, and the difference when moving in the opposite sense, then that accumulated momentum is unaltered by mutual action, and is consequently equal to the product of the sum of the two forces and the time elapsed. And what is true of two forces acting on two particles is true of any set of particles whatever, connected in any way, and acted on by any forces; the accumulated momentum in any direction is always independent of mutual action, and if the forces have a constant resultant in any direction, the change in that accumulated momentum in any time is equal to the product of that resultant by that time. Conversely if we observe that a certain change in the accumulated momentum of a system takes place in a given time, we infer just as certainly that a corresponding force must have operated to produce that change, as, when a certain change is observed in the vis viva of a system, we infer that a corresponding amount of work must have been done to effect that change. Such is the principle of momentum stated in a simple form suited to the problems we are about to consider, and its advantages are, (1) that it is true, irrespectively of mutual action; (2) that we do not require to know the motions of the particles completely, but only their resolved parts in a given direction. On the other hand, we must, in applying the principle, take care to consider *all* the forces which act on the system, and not merely *those which do work*, as in the case of the principle of work: for this reason, amongst others, this principle is not nearly so fruitful of important results in the greater number of mechanical problems as the principle of work; it is chiefly in hydrodynamical problems that it is of great value, and it must always be remembered that, so far from the principle being contradictory to the principle of work, on the contrary, the principle of work is frequently deduced from it in works on theoretical dynamics.*

* In the third corollary to his laws of motion, Newton explains what is to be understood by the total momentum of a system, and proves that it is independent of mutual actions. When the principle of the text is generalised by adapting it to the case of variable forces, and extending it to couples, we obtain

Now the importance of the principle in hydrodynamics arises from the following considerations :—

It was explained above, that in estimating the total momentum of a system we must take into account the direction of motion of each of the moving particles, and hence it appears that if two equal particles move in opposite directions their total momentum is zero. Now cases of fluid motion are common in which for every particle moving in a given direction with a given velocity another equal particle exists, moving in exactly the opposite direction with that same velocity; this, for example, is the case in a complete wave length of a deep water rolling wave and in many other kinds of wave motion; it is also so when a fluid forms a whirlpool about a fixed axis; and thus it comes to pass that the resultant momentum of a fluid is often small, while its vis viva is great. And hence, whatever be the true nature of the process by which work is dissipated in a fluid by "shock," whether it be wholly due to infinitesimal whirlpools, or in part to some kind of mutual action between the particles, there can be little doubt that in estimating the momentum of a fluid mass we need only concern ourselves with the *visible* motions generated in the water without attempting to estimate those *invisible* motions which elude our senses, and the effects of which can only be obtained empirically.

We now proceed to examples, and our first example shall be that of a

Jet of Water Striking a Plane.

A jet of water strikes perpendicularly a plane of indefinite extent, what is the pressure on the plane?

If we follow the course of any particle, at first it is moving perpendicularly to the plane with velocity v (say), then it gradually diverges from the axis of the jet, and at length, after the lapse of an unknown time, moves parallel to the plane—that is,

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the six general equations which are placed at the commencement of modern works on the dynamics of a system of particles, and which simply express the equality which exists between the rate of change of the momentum of the system and the impressed forces considered as acting along and about three given axes.

The couple-form of the principle is useful in the theory of turbines, as Professor Rankine has shown in his work on the *Steam Engine and other Prime Movers.*

its momentum perpendicularly to the plane gradually diminishes, and at length vanishes altogether. Let us now consider the change which takes place in the whole jet in a second; the number and velocity of the particles which at any instant are having their motion gradually changed are always the same, and the change, therefore, consists in the destruction of the momentum perpendicular to the plane of the quantity of water delivered by the jet in 1″. Multiply, therefore, the mass of a cubic foot of water by the delivery in cubic feet per 1″, and that again by v, the result will be the change of momentum in 1″, which, in conformity with our principle, must be the pressure on the plane. The result just obtained can also be derived from the principle of work, if the fluid be supposed frictionless, by an artifice which we have not space to point out, but we here see that it is equally true of a fluid with friction, the only supposition made being that the velocity of the fluid perpendicularly to the plane is wholly destroyed—that is, that nothing of the nature of a rebound takes place from the plane. This problem, which is of primary importance in the theory of hydraulic machines, will be found further developed in Rankine's *Steam Engine*. We regret that our space will not permit us to give some examples of analogous problems,* many of which are of much interest; but as we are especially considering the theory of propellers, we pass on to questions more nearly concerning that theory; first, however, remarking that the above result has been tested by experiment, and found to agree well with theoretical conclusions.†

Vessel Moving through the Water.

When a vessel is towed through the water by a rope, the tension of which is R, the work done by R in moving through a space x is $\mathrm{R}\,x$, and this work is expended in producing visible motions in the water, due to adhesion, friction, or normal pressure, together with certain eddying motions, wholly or partly invisible,

* The formulæ placed by M. Brin at the head of his paper on the jet propeller can readily be obtained, but we do not insert them, as the problem of the jet propeller is so easily solved otherwise, and complex formulæ appear to us simply to divert attention from the real difficulties of the question.

† Many different experiments have been made, which will be found fully discussed in *Rühlmann's Hydraulics*. Leipsic, 1857.

due to friction or improper formation of the vessel's surface. These two kinds of motion, together with any change in the motion of the vessel itself, represent a vis viva exactly equivalent to the work done by R.

Let us now suppose the vessel floating in a sea of finite extent, and let the tension of the rope act during a time t, then, if the resultant horizontal pressure of the finite boundaries of the sea be P, we must have $(R-P)\,t$ as the momentum accumulated in sea and vessel during this time, for the only horizontal forces acting on the dynamical system are these two—namely, R and P. Now, though the assumption is not as obvious as it appears at first sight, we may assume with considerable probability that if the sea be of infinite extent, $P=0$, as it would be if all were at rest, and we shall then have $R\,t$ as the momentum accumulated in time t, just as $R\,x$ was the vis viva accumulated through the space x. It may be asked whether this conclusion be true for an imperfect fluid, and the answer appears to be in the affirmative, only the "stiffer" the fluid the greater must be the sea to make the supposition $P=0$ sufficiently approximate, so that in the limiting case of a solid body no extent of body, how great soever, is sufficient to make this hypothesis true. We therefore conclude *that the tension of the rope must be equal to the momentum generated in the sea and vessel during a unit of time.* To take an example: if a vessel of 8,000 tons displacement be towed by a rope the tension of which is 20 tons, the momentum generated at the end of 10′ is 12,000 second-tons; if the vessel be moving uniformly, this amount of momentum is accumulated in the sea; if, on the contrary, it be initially at rest, and at the end of the 10′ be moving at 10 feet per 1″, then $\frac{8{,}000}{g}\times 10$ second-tons has been generated in the vessel, and there remains $12{,}000-\frac{8{,}000}{g}\times 10$, say 9,500 second-tons, which has been generated in the sea. As has been previously stated, there is reason to believe that the momentum spoken of is represented simply by the visible motions of the water, and not also by those invisible motions which must be considered in applying the principle of work.

We need hardly say that we are not hereby enabled to find out what is the actual motion of each particle of water, nor how much water is affected by the passage of the ship. To obtain

definite results from the principle of momentum, it is always necessary to know the initial and final motions of the water in some definite direction, and besides that, the quantity of water operated on must be known directly or indirectly.

If the vessel, instead of being towed, be propelled by paddles, screw, or other motor, worked by forces within the vessel itself, the momentum generated in sea and vessel is necessarily and always zero, and any forward momentum generated by the passage of the ship is necessarily exactly balanced by backward momentum generated by action of the propeller.

Jet Propeller.—Maximum Efficiency of any Propeller Operating on Undisturbed Water.

The simplest kind of propeller is known as the jet propeller, that kind of propeller in which the water is drawn from the sea by a centrifugal pump, and projected sternwards from orifices in the side of the vessel.

Here the water operated on is originally at rest; it is drawn into the ship and thereby caused to move with a velocity v, the speed of the ship, and is then projected sternwards out of the orifices with a velocity v, which we will suppose known. The real final velocity of the water is then evidently $v - \mathrm{v}$, and if A be the joint sectional area of the orifices, $\mathrm{A}\, v$ is the quantity of water in cubic feet per 1″ which passes through the orifices, and accordingly, if m be the mass of a cubic foot of water, $m\, \mathrm{A}\, v\, (v - \mathrm{v})$ is the momentum accumulated every 1″ in water originally at rest. This can no more be done without the operation of a suitable sternward force than the corresponding amount of accumulated vis viva in the water can be generated without doing an equivalent amount of work, hence it follows that if P be that sternward force,

$$\mathrm{P} = m\, \mathrm{A}\, v\, (v - \mathrm{v}).$$

To understand how this sternward force exerted on the water operates, let us suppose first that, if the pump was not working, the water in the neighbourhood of the orifices would be at rest, or, in other words, that the propeller operates on undisturbed water, then that sternward force operates *solely* through the sides of the passages which conduct the water from the orifices of entry to the orifices of discharge, for the external surface

of the vessel will in this case most probably have no sensible influence on the motion of the water, and therefore cannot exert any force on it. It is only the resultant sternward force which is above determined, and not the intensity of that force at any proposed point; it can, however, be seen without much difficulty that near the orifices of entry it is a forward force gradually urging the water forwards from its state of rest till at length it attains the velocity of the ship, while as the water approaches the orifices of discharge it becomes a sternward force, increasing the velocity of the water till finally it is projected from the orifices with velocity v. The difference between the sternward and forward forces is the resultant sternward force P, the magnitude of which has just been determined. In the case spoken of, when the propeller operates on undisturbed water, this force P must be exactly equal to the resistance of the ship, unless, indeed, the ship be not moving uniformly. Hence, if R be that resistance, it follows that

$$\mathrm{R} = m\,\mathrm{A}\,v\,(v - \mathrm{v}).$$

Our result is independent of the nature and position of the orifices of entry, but we ought not to infer that these are matters of no importance. If these orifices are not so contrived as to admit the water without sensible shock, more water will be set in motion than actually enters the ship, a result equivalent to increasing the resistance of the ship; while if those orifices be placed at a point where the water is considerably disturbed by the passage of the ship, a complex effect is produced, which will be further referred to presently. Meanwhile we go on to consider what conclusions may be drawn from the result just obtained.

The velocity with which the water leaves the ship is $v - \mathrm{v}$, and the half vis viva accumulated in it is, therefore, $\frac{1}{2}\,m\,\mathrm{A}\,v\,(v - \mathrm{v})^2$; if we add to this the useful work done in propelling the ship, we shall have $\mathrm{R}\,\mathrm{v} + \frac{1}{2}\,m\,\mathrm{A}\,v\,(v - \mathrm{v})^2$, which is equal to $\frac{1}{2}\,m\,\mathrm{A}\,v\,(v^2 - \mathrm{v}^2)$; and this must be the work done by the engines in a unit of time, irrespectively of friction and resistance of the water to being forced through the passages. Accordingly the efficiency of this propeller is $\dfrac{\mathrm{R}\,\mathrm{v}}{\frac{1}{2}\,m\,\mathrm{A}\,v\,(v^2 - \mathrm{v}^2)}$ that is $\dfrac{2\,\mathrm{v}}{v + \mathrm{v}}$.

It is not difficult to perceive that this result applies to many other cases, and is, in fact, the maximum efficiency attainable by any propeller which operates in undisturbed water, for it was

explained above that the propeller must necessarily generate a backward momentum equal to the resistance of the ship, while it is evident that the vis viva of the water proceeding from the propeller is wholly wasted; but that vis viva is obviously least for a given sternward velocity when the water is projected directly sternwards; accordingly, if we neglect resistance of passages and friction, the jet propeller is a propeller of maximum efficiency; and, further, the efficiency of any propeller which operates on undisturbed water, and projects it sternwards with velocity v, must be as above $\frac{2\,\mathrm{v}}{v+\mathrm{v}}$, supposing always that no power is wasted in any other way than in giving motion to the propeller race.

From this result we see that the efficiency approaches unity the nearer v approaches v, while referring to the formula $\mathrm{R} = m\ \mathrm{A}\ v\ (v-\mathrm{v})$, we see that, the smaller $v-\mathrm{v}$ is, the greater must be A, and hence we conclude that, other things being equal, the efficiency of a propeller is greater the greater the quantity of water on which it operates. We shall have occasion to mention this hereafter.

Our space will not permit us to discuss the case where the water operated on is disturbed by the passage of the ship, and we besides do not wish in the present article to enter on questions which are not as yet completely understood. We merely remark in passing that it is believed that in most cases the efficiency of a propeller is reduced by this cause. M. Brin, indeed, maintains in the paper above alluded to that the efficiency of the jet propeller can be made unity by placing the orifices of entry at the stern. This, however, does not seem possible, for to realise a propeller of efficiency unity we must take all the water set permanently in motion by the ship, and must project it backwards with such a velocity as to reduce it to rest. It is evident that if the ship and propeller together leave behind it any water possessing permanent motion, then all the accumulated work in that water will be wasted. The reasoning by which M. Brin obtains his result does not depend on any consideration of disturbed water, but appears to assume that the pressure at the orifices of entry can never be less than the hydrostatic pressure due to the depth of the orifices, an assumption which amounts to supposing that no force is required to draw the water

into the ship. In the other cases M. Brin* makes no similar assumption, and hence has arrived at a result agreeing with ours. We are certainly disposed to believe that the obvious view of the subject is the true one—namely, that the stern is the most unfavourable position for the orifices, but to give reasons would require a long discussion.

Some of the results of this section can be obtained by the principle of work alone, but we have not space to give the reasoning. We now pass on to

Feathering Paddles.

We have already said that the principle of momentum will not produce definite results unless we know independently the initial motion of the water, the final motion of the water, and the quantity of water operated on. For these data we must have recourse to observation in every case. In feathering paddles the obvious phenomena are the great streams of water issuing from the paddles. Initially this water is at rest, while finally it moves as is usually supposed with a velocity (v) equal to that of the paddle-floats, an assumption which apparently cannot be far from the truth. If, then, $Q = A\ v$ be the quantity of water operated on per 1″, the momentum accumulated in the streams in every second must be $m\ Q\ (v - \mathrm{v})$, which, again, assuming that the water amidships would be at rest if the paddles were not working, must be equal to the resistance (R) of the ship. Moreover, the half vis viva of the streams will be $\frac{1}{2}\ m\ Q\ (v - \mathrm{v})^2$, and is consequently equal to $\frac{1}{2}\ \mathrm{R}\ (v - \mathrm{v})$. Now the useful work done per 1″ is R v, and the power exerted by the engines, irrespectively of friction and other resistances to be mentioned presently, is R v, whence the power wasted is $\mathrm{R}\ (v - \mathrm{v})$. Thus we see that the power wasted in producing that motion in the water which is necessary in order to obtain the required propelling reaction is only one-half the whole waste, a result characteristic of all propellers operating on the water with uniform velocity. One condition of maximum efficiency in a propeller is the same as that in any other hydraulic machine—namely, that during

* M. Brin's reasoning is not always easy to follow, but if the reader compares Section 7 of his Memoir with the mode by which he deduces equation (9) of Section 5 from equation (8) of the same section, it will be seen, we think, that something like this is assumed.

entrance to and the whole passage of the water through the machine, there should be as little "shock" as possible, a condition which is violated by paddles, as is shown by the violent dashing about which the water undergoes under their action. Our investigation shows that this "churning" absorbs as much work as is required to obtain the propelling reaction; and, in fact, more than as much is thus absorbed, for we have neglected the resistance to forcing the floats in and out of the water, a process giving rise to vertical forces not taken into account in the preceding investigation, but which increase the work done by the engines, so that the efficiency of paddles is somewhat less than $\frac{V}{v}$.

It may now be of some interest to compare roughly the efficiency of the jet propeller and feathering paddles, and for this purpose we shall suppose that the great technical difficulties which would arise from the use of large orifices have been overcome, so that our jet propeller sends back the same quantity of water with the same velocity as feathering paddles of 20 per cent. slip, for which the orifices must be somewhere about the same size as the paddle-floats. Then the power wasted by the paddles will be 10 per cent. in the race, and from 25 to 30 per cent. in "churning" the water and engine friction, while the jet propeller will waste 10 per cent. in the race, and at least 35 per cent. in engine friction and resistance of passages. Though it is generally agreed that the jet propeller has not yet been tried under favourable circumstances, we imagine most of our readers will agree with us in thinking 35 per cent. a low estimate. But it will be seen that even thus the jet propeller is not so efficient as paddles, while in practice the jet area must be reduced, when, as shown above, the comparison becomes yet more unfavourable. Besides the practical difficulties in the way of large orifices there is this objection, that if the orifices of discharge be placed under water they will add greatly to the resistance of the ship, while if they are placed clear of the water, work must be done to raise the water passing through them above the sea level; with large orifices the work so spent would be a very considerable item.

Screw Propeller.

The screw propeller is vastly more complex in its action than

either of the simple propellers we have been considering, for three reasons:—(1) the action is oblique instead of direct; (2) the velocity of each particle of water acted on by the propeller is not the same; (3) the screw always operates on water which has been previously disturbed by the passage of the ship, and the difficulties thus created are so serious that at present the problem cannot be said to have received complete solution. It would be impossible for us to enter on this question at the end of an article already too long; we shall therefore confine ourselves to a remark on oblique action which immediately follows from what has been said.

Oblique action is always, other things being equal, a cause of inefficiency in a propeller, as has been sufficiently explained above, and it may be asked how this is consistent with the fact that the screw propeller is a practically efficient propeller. The principal and probably the only answer to this question is, that a screw of large size operates on a vastly greater body of water than any paddle-floats which could be put into the same vessel, and it has been shown above, that, other things being equal, the efficiency of a propeller is greater the more water passes through it. Yet no doubt it is conceivable that in some cases there might be less "churning" in an oblique acting propeller so as partially to balance the loss by lateral motions.

In conclusion, we must say that it is hardly possible to do justice to the subject within the limits of a few pages; we shall be content if we have succeeded in showing that the modern theory of propulsion is something more than a mere hypothesis, resting, as it does, on the secure basis of an old and well-known mechanical principle, interpreted and applied in a manner suitable to the problem under consideration.

COMPOUND ENGINES, WITH ESPECIAL REFERENCE TO THOSE IN SHIPS OF WAR.

By W. J. Pratten, Fellow of the School, late Engineer R.N.

One of the most important subjects connected with Marine Engineering is that relating to compound engines, and, whether considered with reference to the economising of fuel, or in regard to that scarcely less important point, the employment of high-pressure steam in marine engines of large size, it is equally instructive. With the introduction of superheated high-pressure steam and surface condensation, great changes were necessary in the internal arrangements of engines and boilers. The high temperature of the steam caused great wear and tear in the cylinders, and the boilers rapidly deteriorated under the influence of feed-water impregnated with copper. But the primary object in introducing this type of engines was to economise fuel; not, however, with the view of postponing the fatal day that is to exhaust our coal-fields, but to enable ocean steam-ships to carry a greater number of days' coal in the same space than they are able to do with simple engines.

Though the efficiency of the best compound engines falls far short of the ideal efficiency of a perfect engine, and still further short of the theoretical value of the fuel burnt, and from the nature of the case must ever do so, yet we ought to greet with approbation every advance made in that direction. That the saving is great is undeniable, and in spite of objectors the compound type, for some years past, has met with increasing favour in the mercantile service, until we find at the present day that nearly all new steamers intended to make long passages are so fitted. But during the same period the type has made slow progress in the Navy; indeed, until quite lately scarcely any *real* advance was made; for the experience gained from the first compound engines introduced was not of that satisfactory character to induce much confidence in the principle.

We do not intend in this article to give a detailed account of all the varieties of arrangement to be found in compound engines, but merely to glance at those generally adopted in merchant steamers, and to notice more particularly those we find in men-of-war; for though the latter are few in number, they differ greatly in design, and, with two or three exceptions, include every type to be found in sea-going vessels.

The engines of merchant steamers constructed on this principle may be divided for convenience of consideration into three classes. In one, the high-pressure cylinder is placed side by side with the low-pressure cylinder, the cranks being at angles varying from 90° to 150°. In another class, where the engines are mostly of the inverted type, the high-pressure cylinders are placed on the top of the low-pressure, the pistons being on the same rod. In the third class, which is the simplest arrangement, we have a single engine of the second class instead of a pair of engines, a heavy fly-wheel being attached to the screw-shaft, to equalise the speed of the engine.

The object of placing the cranks at an angle greater than 90° is to lessen the back pressure in the small cylinder, by giving a more regular flow to the steam between the two cylinders. If the cranks were placed opposite to each other—viz., at 180°—which has been done in some cases, there would then be no interruption to the flow of steam, and the indicator diagrams would not be distorted. But in avoiding this evil we meet with one of a different character. When the cranks are at right angles, and the work done in each cylinder equal or nearly so, the difference between the maximum and minimum tangential pressures on the crank-pin is not very great; but every increase in the angle between the cranks rapidly increases this difference, and at the extreme case of 180° apart, while the maximum pressure is greatly in excess of what it is when the angle is 90°, the minimum pressure diminishes twice to zero every revolution. An uneven motion of the engine follows from the variation, great strains are thrown upon the moving parts, and consequently there is an increased liability to break down. The best method for steering between the two evils is to have a large reservoir for the steam in its passage between the two cylinders; this greatly reduces the back pressure in the small cylinder, and avoids increasing the strains on the crank-shaft.

This reservoir is not required in engines belonging to what we have called the second class; for both pistons being on the same rod, at the completion of the stroke the steam passes direct from the high-pressure cylinder into one from three to four times its capacity, and we get no undue back pressure. As a rule they make good working engines, especially those of the inverted type; but they require more room, are more costly, and of greater weight than the other classes. In some cases ordinary simple engines have been altered to this plan with most satisfactory results; for they have obtained an increase in power, with an increased speed of ship, and a decrease in the consumption of fuel.

In the third class, or single engine with high and low pressure, the tangential pressure on the crank-pin becomes zero at the dead points; it is absolutely necessary, therefore, to have a heavy fly-wheel, and also a small auxiliary engine, to assist in starting, if the crank-pin is at the dead points.

At first sight it would seem that a fly-wheel with a heavy rim is strangely out of place in a sea-going steamer, on account of the severe strains brought upon the screw shafting by the engine's racing, as well as by the pitching of the vessel. It may be thought, too, that the wheel itself under such circumstances would break up, as we have known the fly-wheel of an auxiliary engine driving a centrifugal pump to break up from the racing of the engine by the pump losing the water, combined with the violent pitching of the vessel in a heavy gale of wind. We believe, however, that in Messrs. Holt's line of steamers, engaged in the China trade, which are fitted upon this plan, no accident of the kind has occurred. The length of the vessels is in their favour, and the risk is still more diminished by supplying the engine with a sensitive governor.

In respect to economy of fuel these engines of Messrs. Holt's are very successful. They are generally about 200 nominal H.P. in vessels of 2,000 tons, the consumption of coal per day varying from 10 to 14 tons, giving an average speed of 8 knots in the long voyage to China. The average consumption per indicated H.P. per hour is but little over 2lbs., and this is not more than half what is burnt by what are considered good engines of the ordinary marine type. It is true that the cost of repairs is greater with cylindrical boilers, worked at a pressure of from 60 to 70lbs., than with box boilers, worked at 20 or 30lbs., the latter not using the

condensed steam; but the saving in stowage-room and in coals is also great, and more than compensates for first outlay and additional repairs.

In some compound engines, generally those with four cylinders, the steam is not used at a higher pressure than 30lbs., consequently it is not to be expected that such good results of low consumption can be obtained; for, as a rule, unless there are grave defects in design, as you increase the pressure of steam you decrease the consumption of fuel. The merits of the compound system are not seen to advantage in this variety; in fact, many engines belonging to it have proved total failures.

There are cases of the employment of steam of higher pressure than that mentioned above; but its use is confined chiefly to small vessels used on rivers, such as tugs, &c., where large boiler power is not required. It is the question of boilers that hinders in some degree the extension of the compound type; for, if steam is used of 60lbs. pressure in lieu of 30lbs., it is found advisable, if not absolutely necessary, to employ 50 per cent. more boilers; in addition, the cylindrical form must be adopted, and of limited capacity, to enable it to withstand the strains to which it is subjected. A demand for a still stronger boiler is best met by reducing the diameter of the shell and furnaces, consequently, by a diminution of the grate and heating surfaces; necessitating with powerful engines additional boilers. These additions and their requirements increase the first cost, and though somewhat less water and steam room in boilers is needed with the use of high-pressure steam, yet from their less compact form the advantage of saving stowage space is lost, which is of first importance in cargo steamers, and most desirable in ships of war. These and some other considerations retard the general introduction of engines which must ultimately supersede all others.

At the end of this article are appended extracts from the log of the Royal mail steamship *Tasmanian*, with which we have been favoured by Mr. S. Thearle, late student of the Royal School of Naval Architecture, through the kindness of Messrs. John Elder and Co., of Glasgow. Both voyages were made under nearly similar conditions in regard to the weather, but in one voyage the ship was driven by simple engines of the inverted type, and in the other by compound engines constructed by the above firm; with these the expenditure of fuel was reduced more than one-half.

We propose now to consider those engines belonging to our subject that we find fitted or that have been fitted in the ships forming part of our Navy. They are not very numerous, but the range in power and tonnage is wide. The ships include those of upwards of 4,000 tons and those under 300 tons, while the nominal H.P. varies from 700 to 60, the greatest developed power reaching nearly 4,200. They may be divided into three classes respecting size and power—a frigate, sloop, and gunboat class. To the first belong four—viz., two Indian troop-ships, an iron-clad, and a wooden frigate. It is important to remember that they were the first so fitted, consequently their engines have had a severer trial, and greater experience has been gained from their performances, than from those supplied at a later date. The engines were as follows:—

Crocodile	...	700 H.P.	...	Messrs. Humphrys & Tennant.	
Serapis	...	700 H.P.	...	Do.	do.
Pallas	...	600 H.P.	...	Do.	do.
Constance	...	500 H.P.	...	Messrs. Randolph & Elder.	

The engines of the first three were of the same kind, horizontal compound on Woolf's principle, the high-pressure cylinders being fastened behind the low-pressure, with each set of pistons carried on the same rod and separated by a distance-tube, their weight being supported by a single trunk at the midship side, and by the prolonged piston-rod on the wing side. (We may mention here that this is not the present arrangement in the troop-ships, these engines having been replaced by simple ones for reasons we shall give hereafter.) In the *Pallas* the diameters of the high and low pressure cylinders were 51 and 102 ins. respectively, diameter of trunk 2·6ft., with a stroke of 3·25ft. In the troop-ships the cylinders were 57 and 102 ins., diameter of trunk 3·0ft., and the stroke 3·75ft. The relative capacities of the cylinders in the former case (allowing for the trunk) are about as 4 : 15, and in the latter as 1 : 3. The pressure of steam was 30lbs., and the cut-off at full $\frac{7}{8}$ of the stroke in both cylinders, the jackets of which were supplied with superheated steam. They had surface condensers of the same size, the tubes being of copper, with a large area of cooling surface, the water being circulated by two centrifugal pumps.

The engines were designed to work up to six times the nominal power, which was exceeded in the ironclad, but barely

reached in the troop-ships. During the trials no exact estimate of the coal consumed was taken, but it cannot have been less than 3lbs. per indicated H.P. per hour. This allowance, if correct, is not unfavourable to the engines, though it has now been greatly surpassed; but the speed they were driven at, and the lowness of the steam pressure employed, ought to be duly considered.

A few months' work began to tell upon the weak points of their construction, and one of the most apparent defects was the rapid wear in the high-pressure cylinders, caused by the thrust of the connecting-rod exerting an upward pressure upon the large piston, which necessarily threw the whole weight on the small piston and back piston-rod. The latter, being of small dimensions, had not sufficient surface to bear the strain with impunity, and rapid wear was the consequence. In one troop-ship, after eight months' service, during which time she had steamed 31,000 miles, it was found necessary to replace the ends of the piston-rods with small trunks (a plan which has since been adopted in other large engines not on the compound principle), and, moreover, to bore out the small cylinders $\frac{3}{4}$-inch larger, they having worn down nearly $\frac{3}{8}$-inch. It cannot be said here that the size of the castings affected the metal, for they were but small ones.

The increased support given by the additional trunk greatly modified the wear, but there were other grave defects, and a most important one was the difficulty of adjusting the gudgeon bearings within the large trunks, of the condition of which under steam it was impossible to judge accurately. Other sources of trouble were the cylinder jackets, which were formed by wrought-iron plates attached on the convex surfaces of the cylinders, and the unequal expansion of the wrought and cast iron when heated caused leaks which were not preventible. A waste of steam also took place from the high-pressure cylinder to the low one, through the gland in the diaphragm through which the piston-rod worked.

In the *Pallas*, from the smaller amount of work done by the engines, and that at a slow speed, the wear of the cylinders and gudgeon was not so marked, but in the two troop-ships it was thought advisable after a few months' further trial to substitute single cylinders of 96ins. diameter for the compound ones, con-

verting them into what are termed *direct-acting* engines, with the piston of each carried on a 12-inch rod, the ends being supported by slipper guides. It is not alone in the Navy that this variety of compound engine has failed to meet the exigencies of a fair amount of work, for in several of our largest ocean steamships it has been necessary to make a similar alteration.

Before leaving this arrangement it may be asked which engines in the troop-ships gave the best results? As regards economy of fuel the compound had the advantage, but the cost of repairs and supervision after every run more than counterbalanced the saving in fuel. An average speed of 10 knots was maintained in long passages with a consumption of $2\frac{3}{4}$lbs. of coal per indicated H.P. per hour, whereas with the simple type, under similar conditions, the expenditure exceeded $3\frac{1}{2}$lbs. It may be said, perhaps, that the consumption was not very low, but it must not be forgotten that comparisons are unjust between trials lasting a few hours and those extending over weeks.

We pass on to describe the engines of the *Constance*, one of several competitive wooden frigates; but as their arrangement may be considered obsolete, like the vessel, it is not necessary to dwell upon them, though there are excellences in the design to repay an examination. They are inclined engines, with six cylinders, two high-pressure of 60ins., and four low-pressure of 78ins., arranged three on each side of the crank-shaft, the high-pressure cylinders between the others. The crank-shaft has three cranks, the two end cranks being in the same direction and opposite to the middle one. In order to turn the centre, the corresponding piston-rods work at right angles on each crank. By this arrangement the pressures on the crank journals and main bearings are equalised for every position, and no power is lost by friction, except what is due to the weight of the shaft, provided the work done by each of the low-pressure cylinders equals half the work done in each high-pressure cylinder. But in the measured mile trial this was not the case, and it is doubtful if the friction of the extra pistons did not counterbalance the advantages of equalising pressures on the shaft. Moreover, the multiplication of cylinders demands large space, and requires a complicated slide gear, besides being more expensive to construct. During her first and only commission the engines were not to be depended on, for more than once they failed at critical moments, and it is

not too much to say that an ordinary amount of steaming must have condemned them to the scrap-heap.

Such has been the success attending the earliest compound engines. Let us turn now to those in the sloop class of ship using a higher pressure of steam. These are the—

Sirius	... 350 H.P.	... ...	Messrs.	Maudslay & Field.
Spartan	... 350 H.P.	... ...	„	Rennie & Sons.
Briton	... 350 H.P.	... ...	„	„ „
Tenedos	... 350 H.P.	... ...	„	Randolph & Elder.
Thetis	... 350 H.P.	(completing)	„	Rennie & Sons.

Of the *Sirius* we have not much to observe. The engines have two high-pressure cylinders of 34ins., and two low-pressure of 75ins., the latter jacketed with superheated steam. They worked satisfactorily on trial, developing nearly $6\frac{1}{2}$ times the nominal power, the ship exceeding the estimated speed. The boilers were worked at 54lbs.; the consumption of fuel per indicated H.P., though less than in the cases above, was not so low as in some to follow.

The engines of the *Spartan* are also horizontal, and of the return connecting-rod class, but on Allen's compound principle; and we have no hesitation in saying that they bear the palm for inefficiency among the compound type in the Navy. With an arrangement of cylinders open to grave objection from its opposition to first principles, together with difficulty of access to the working parts, they combine an expenditure of fuel, when working at full speed, which is not exceeded by many engines of the simple type using steam of 20lbs. pressure. We will give an outline of their construction. Each engine has a long cylinder of 64ins. diameter, divided by a diaphragm into two equal parts. There are two pistons of the same diameter as the cylinder, connected together by a trunk of 55ins. diameter, which works through a gland in the diaphragm, metallic rings being used for packing. The high-pressure steam acts on an annular surface $4\frac{1}{2}$in. wide, the area of which is to the area of the piston as 1:4, and this is the ratio of the volumes for high and low pressure steam in the cylinder. From this brief description, some glaring disadvantages are at once apparent. The same cylinder is devoted to two different purposes every alternate stroke; and on the communication between the cylinder and the condenser being established, the concave surface of the former is rapidly cooled down,

and though it may be checked by receiving heat from the superheated steam in the jacket, the result must be prejudicial to the efficiency of the engine. Another serious loss arises from the escape of steam around the trunk, which increases the back pressure, and was very noticeable in the indicator diagrams taken on various trials. There is nothing worthy of remark about the other parts of the engines except the one surface-condenser serving for both engines, the water being circulated about the copper tubes by a centrifugal pump. The boilers, six in number, are cylindrical, 10ft. in diameter, with two furnaces 5ft. 6in. long and 3ft. 3in. internal diameter in each.

The estimated speed of the ship and indicated H.P. have never been realised. In one of the first trials with the boilers worked at 70lbs., something like five times the nominal power was obtained, and the speed was over 12 knots; but with the pressure reduced to 60lbs. we find, after a number of trials at full speed, that the indicated H.P. was only 1,256, with a consumption of 4¾lbs. of fuel per indicated H.P. per hour, and the speed little more than 11 knots. It may well be asked, where does the great waste occur? In the boilers or engines? The indicator diagrams show a considerable amount of back pressure, and that the steam is much wiredrawn. These conditions are sufficient to account for a great loss of power, which is owing, without doubt, to the leakage of steam about the trunk, to confined steam passages, and perhaps to the action of the slides. Some accident, trivial or otherwise, attended each of the numerous steam trials; on one occasion the slides wanted readjusting; on another a high-pressure slide broke up under the steam pressure, and so on; but there was always a deficiency of indicated H.P., to increase which all varieties of coal that promised good evaporating powers were tried. Almost without exception, however, each trial exhibited a less satisfactory result than the preceding one, showing such a decline of efficiency as might be expected from an old pair of engines much worn. The *Spartan* has lately been commissioned, and a few months, if she steams frequently, will test the value and durability of her arrangement.

Hitherto the engines we have described belonging to our Navy have had more than two cylinders, or what, as in the last case, corresponded to more than that number; we come now to the simpler form, having only one high-pressure and one low-

pressure cylinder arranged side by side. The *Briton*, *Tenedos*, and *Thetis* have this class of engine; the latter has not been tried yet.

We propose to examine the arrangements in the *Briton* and *Tenedos* together, because they embrace rival methods of jacketing and reheating the steam; moreover, they have competed for supremacy in economy of fuel at different speeds. The cylinders of the *Briton* are 57in. and 100in. nearly in diameter; they are fitted with double piston-rods, the large piston having a back trunk to give additional support. Their volumes are as 1 : 3, and both are jacketed with super-heated steam, as are also the pistons. The jacket is not cast with the cylinder, but formed by a bush of cast-iron 2in. thick, which is well secured. The steam, on its exit from the small cylinder, passes through Cowper's reheating apparatus before reaching the large cylinder. The external appearance of this apparatus resembles a large pipe; but it is divided internally into several longitudinal compartments; the inner and outer are filled with superheated steam, and the intermediate one with the cooler steam from the cylinder, which has its temperature raised by contact with the heated metal of the apparatus.

In the *Tenedos* the cylinders are 57in. and 90in. in diameter, the volumes being as 2 : 5. They have double piston-rods, and a back supporting rod to each piston. The steam on its passage between the cylinders enters a large receiver, which is placed around the small cylinder, making it of the same size as the other. The steam in this reservoir takes heat from the convex surface of the cylinder steam-jacket. The large cylinder is also jacketed, as well as both pistons. A large capacity for this reservoir of steam is most essential to engines of this pattern. It diminishes the back pressure in one cylinder, and accumulates a head of steam for the other.

There is a close resemblance in other parts of the engines; they are both provided with an expansion-valve capable of giving a high expansion to the steam. The cranks are at right angles, with return connecting-rods. The boilers are six in number, 10ft. in diameter, with two furnaces in each, worked at a pressure of 60lbs. The heating and grate surfaces are nearly the same in both cases.

It is contended by some engineers that the practical results obtained from steam-reheaters do not justify their adoption, and

instances can be given where positive advantages were gained by discontinuing their use. But on referring to the experimental trials of the ships in question, we find at full speed the smallest consumption of fuel in the one fitted with Cowper's apparatus, but at lower speeds it is slightly in favour of the other. We give the results:—

	Briton.	*Tenedos.*
Speed.	Per I.H.P. per hour.	Per I.H.P. per hour.
8 knots	1·6 lbs.	1·55 lbs.
10 „	1·55 „	1·35 „
Full speed (over 13 kts)	1·98 „	2·3 „

In both cases the weather was favourable. The alleged reason for the rapid rise in the consumption in the *Tenedos* was owing to the wind having fallen light, necessitating the use of a strong steam-blast. At ten knots the quantity of fuel consumed was least, showing conclusively that the slowest rate of combustion was not attended with the best results, and this applies to other engines, for with light fires heat is carried off by undecomposed air passing through the furnaces. With this speed also the engines developed nearly one-half of the indicated H.P. of which they were capable, which proportion of power in all engines gives a close approximation to the highest obtainable economy. Moreover, the work done in each cylinder was nearly equalised, in which case the difference between the maximum and mean twisting moments is not large, and a steady uniform motion is given to the crank-shaft.

There is one feature in the mode these trials were conducted which, in our opinion, is open to censure. To guess at the quantity of fuel in the furnaces, and then after a few hours' trial to endeavour to leave them in a similar condition, is a rough way of estimating the consumption, and allows room in twelve large furnaces for an important difference between the real and reputed consumption of fuel per indicated H.P., especially with reference to moderate speeds.

There remains now but to consider the arrangement in the third or improved gunboat class. There are seven of the same design in various stages of progress to be fitted with engines of the same pattern 60 nominal H.P., made by Messrs. J. Watt and Co., but at present only two are engined, the *Coquette* and *Foam.*

They are constructed on a similar principle to the engines of

the *Tenedos*, with a high-pressure cylinder of 31in., and a low-pressure cylinder of 48in. diameter; they have return connecting-rods, and a single condenser between the sets of rods. The cylinders are in one casting, bushed and jacketed, with the reservoirs around both. The pistons are supported by back rods, but are not super-heated. The boilers, two in number, are cylindrical, 6·5ft. in diameter, with two furnaces in each, with iron tubes in rear of them, and are worked up to 60lbs.

We believe that neither of the vessels mentioned above has had an official trial, but from their large boiler power and capacious cylinders, there can be little doubt of the indicated H.P. approximating to 400, with a consumption of fuel, as low as 2lbs. per H.P., comparing very favourably with the engines of the old gunboats of the same nominal power, but with a very different real power. In the latter respect no better instance can be given of the absurdity of our present nomenclature of *nominal* H.P.

The compound type is eminently suited for vessels of this class, which are mainly employed on stations where there is much cruising, and where inferior coal at times fetches a fabulous price. On other stations the ships of war that do the work of cruisers have not, as a rule, sufficient steaming to thoroughly test the merits of any particular principle involved in their construetion. There are, however, ships engaged in duties requiring them to be frequently under steam to which the type is admirably adapted, such as store and some particular service ships, wherein the most successful variety of the type might be adopted without any detriment to the duties they perform. But in them, with scarcely an exception, we find the most obsolete engines yet afloat, greatly under-powered and most extravagant in fuel. With the numerous advantages derivable from a judicious selection and use of compound engines, it is not gratifying to contemplate how small a percentage of ships of war are so supplied, while in the mercantile marine they are largely represented.

The wide range of the subject has compelled us to limit our attention to a cursory glance at its main features—to indicate the defective as well as the commendable parts of various designs, and the gradual though sure advance made towards perfection; but we have throughout avoided constructive details, which interesting matter we leave for further consideration.

ABSTRACTS OF LOGS OF R.M.S. "TASMANIAN," 600 H.P.,

From Southampton to St. Thomas. Length of Ship, 335ft.; Breadth, 33ft. 6in. Tonnage O.B.M., 2,460.

No. 1.—Thirty-Fourth Voyage, with Vertical Trunk Engines.

Date 1866.	Revolutions per Minute.	Steam Gauge.	Distance Run by Ship.	Distance Run by Screw.	Coal expended.	Time steaming.	REMARKS.
Sept.	No.	lbs. per sq. in.	Miles.	Miles.	Tons. Cwt.	Hrs. Min.	
3	...	...	...	...	...	...	At 3.40 set on full speed for St. Thomas.
4	40·2	15	209	267	59 10	20 20	Head-wind, with confused sea. Weather thick, with rain.
5	39·1	15	190	310	64 5	24 15	Strong head-wind, with heavy head-sea. Ship pitching a good deal.
6	37·4	15	155	296	63 17	24 15	Strong gales of head-wind, with head-sea; 10 p.m., engines eased to half speed for 4 hours.
7	36·8	15	193	290	64 4	24 6	Strong head-wind, with heavy head-sea; shipping heavy seas.
8	41·3	15	243	327	71 15	24 12	Strong head-wind, with heavy head-sea; all working well.
9	41·6	15	179	294	70 6	24 13	Strong gales of head-wind and heavy head-sea.
10	42·5	15	275	336	74 12	24 20	Wind on port beam, with heavy beam swell; fore & aft sails set.
11	42·7	15	274	326	73 4	23 15	Ditto, with heavy beam sea; 9.50 p.m., stopped for 50 minutes.
12	44·5	15	292	350	79 14	24 9	Calm weather; sea smooth.
13	45·0	15	300	358	82 0	24 23	Wind on port beam; fore and aft sails set; weather fine.
14	44·3	15	299	351	81 17	24 17	Light head-winds & fine weather. Sea smooth.
15	44·7	15	307	356	89 2	24 13	Ditto ditto ditto.
16	44·0	15	292	347	85 3	24 13	Calm weather; sea smooth.
17	43·3	15	291	342	81 4	24 15	Ditto ditto ditto.
18	42·6	15	175	205	47 15	24 40	Ditto ditto. At 2.40 a.m. stopped at St. Thomas.
	42·0	15	3,674	4,755	1088 4	359 6	

No. 2.—Fifty-First Voyage, with Compound Engines.

Date 1871.	Revolutions per Minute.	Steam Gauge.	Distance Run by Ship.	Distance Run by Screw.	Coal expended.	Time steaming.	REMARKS.
April.	No.	lbs. per sq. in.	Miles.	Miles.	Tons. Cwt.	Hrs. Min.	
17	...	...	...	...	...	...	At 3·30 p.m. set on full speed for St. Thomas.
18	44·1	40	202	248	27 0	20 40	Strong head-winds and heavy head-sea.
19	42·4	40	197	283	28 7	24 15	Ditto ditto ditto.
20	35·3	35	152	235	20 15	24 15	Strong gale of head-wind and very heavy head-sea.
21	42·2	40	204	280	27 16	24 20	Strong head-wind and heavy confused sea.
22	49·0	45	262	325	34 1	24 20	Fresh head-wind with head-sea.
23	49·7	45	290	332	34 11	24 15	Light head-wind, with westerly swell.
24	49·1	45	307	330	33 9	24 20	Wind on starboard bow; two sails set not doing much good.
25	49·0	45	300	328	32 13	24 10	Calm weather with a little swell.
26	48·0	45	283	324	35 1	24 10	Wind light on port bow, with fine weather.
27	48·0	45	287	325	36 8	24 15	Wind variable with ground swell.
28	48·3	45	300	325	37 14	24 20	Light fair wind with fine weather. No sails.
29	48·5	45	285	325	37 12	24 15	Ditto ditto ditto.
30	48·4	45	300	325	37 14	24 15	Ditto ditto ditto.
May 1	48·5	45	290	328	39 2	24 25	Ditto ditto ditto.
2	48·5	40	28	31	3 10	2 15	At 2.15 p.m. stopped at St. Thomas.
	46·6	43	3,687	4,344	466 3	388 30	

THE MARINE CYLINDER AS FITTED IN THE NAVY.

By A E. Seaton, Student of the School.

Perhaps the most important improvements made during the last ten years in the marine engine have been in the design and construction of the cylinder, and naturally so, since it plays so prominent a part in that greatest of all considerations, the economy of fuel. But the designer is not free to study this point alone; he is restricted by questions of prime cost, of durability, of space, and in the Navy by the necessity of keeping the engines below the water-line.

Every maker has introduced his own modifications, and it has only been by slow degrees, and by a species of *natural selection*, that the excellence realised in our large ocean cruisers has been attained. But no one will deny the need of still further improvement—no one, at any rate, acquainted with the lengthy catalogue of cylinders broken year by year in Her Majesty's Navy.

But how to gain increased strength is rather a vexed question. Experience teaches that mere thickness of metal will not suffice, for Messrs. Maudslay's heavy castings are no more infallible than Messrs. Penn's light ones. Nor does mere theory help us much in the matter, for every designer knows the thickness of metal calculations from considerations of pressure alone would give, and any other calculations are much too complicated for general use. There is, too, a limit of thinness to which a cylinder can be cast, even when neglecting for the time the consideration of the strains it would have to bear.

We have not as yet hit on the right metal, but for the present cast-iron is the stern necessity; still in fairness it should not be held responsible for all the failures in design. It was only a few weeks ago that an iron-clad frigate arrived at the port where she was to be fitted out with both her cylinders cracked, and that extensively. The crack in the forward cylinder extended 36″ parallel to and 2″ from the steam orifice at the cover end; it had occurred in the junction of the steam passage with the barrel, and the cause was obvious. For

a space of several feet—in fact, as far as could be seen through the exhaust port (and the engines were of 800 nominal H.P.), the junction was not strengthened by web or gusset, nor even by a beading in the angle. The bending moment on this part must have been excessive, as the strain on the cylinder cover was in a great measure taken here in consequence of the connections of the flange with the steam passage. The cylinder was also cracked in the bottom, probably either from the great tension induced by unequal contraction after casting (the jacket and cylinder being cast in one), or from the too rigid bolting to the engine-bearers.

This question of bolting down has not been yet satisfactorily solved. It is of course evident that the cylinders should not be bolted down rigidly by both ends, for the expansion on heating would cause distortion of form, and thus throw great strains on their lower parts and also on the holding-down bolts. The usual plan is to make a firm connection to the front bearers, and longitudinal expansion is allowed for by making the holes in the back and side flanges oval.

But even with this arrangement, fracture of the cylinders is said to have taken place in consequence of the giving of the ship in heavy weather, and the strain thus thrown on them through the holding-down bolts. It is worthy of consideration whether it would not be expedient either to do away entirely with back holding-down bolts and extend the engine frames further over the cylinder front, or else allow a space between the bolt-heads and back flange, and fit set screws that could be tightened up against the bolts when the cylinder was thoroughly heated and had expanded to its full extent.

Another point to which attention may be drawn is the very small independent support given to the valve-boxes; these are either cast with the cylinder, or more generally bolted to the cylinder face, and take nearly the whole weight of the immense valve, and the weight of the expansion valve and case, in addition to numerous other fittings. The strain thus caused is transmitted to the side of the cylinder either wholly, or partially when supported by one of the main webs; is it to be wondered at, then, if some cylinders split across the face longitudinally and require patching after a few months' work?

It is only lately that makers of these large marine engines, in order to reduce the strain and friction on the bottoms of cylinders,

have supported the pistons with back-rods either solid or hollow. Messrs. Penn have always done so in their trunk engines, and although the drawback is said to be the very great friction, still the maintenance of the cylinder's interior in good condition is a fair set-off to this. As an advantage of this support to return connecting-rod engines we may instance the case of H.M.S. *Agincourt*, whose cylinders, after merely steaming from Liverpool to Devonport and on two or three trial trips, were found to be very deeply scored. In 1870 she was fitted with hollow cast-iron back rods, one bolted to each piston and working through a hole in the cover on gun-metal guides, and enclosed in a cast-iron case bolted to the cover, and this change has very materially improved the working of the engines. Messrs. Humphry and Tennant, in their engines, have extended the piston-rod through a stuffing-box in the cover, and fitted the end into a brass shoe working on a cast-iron bracket-guide bolted to the cover, and the further end supported by rods from the cylinder-top, and this method seems more efficient than that just described.

The difficulties of construction have been further increased by the addition of the steam-jacket, comparatively new to the marine engine, although used by Watt in his land engines to insure economy. Formerly with a low initial pressure of steam and a late cut-off, the expansive powers of steam were little utilised; when these conditions were reversed and a high pressure employed, and by expansion valves a quick cut-off obtained, it became necessary, in order to enjoy the full advantages of expansion, that heat should be applied during the process. This was effected by partially surrounding the cylinder with a casing into which steam was admitted from the boiler. The employment of still higher pressure has led to the necessity of greater degrees of expansion, and to do this compound or combined engines have been introduced.

H.M.S. *Constance* was the first ship fitted with this class of engine by Messrs. Randolph and Elder, and competed with two sister frigates in a race from Plymouth to Madeira in 1865. She won the race, with a consumption of coal, a little over 2½lbs. per I.H.P., much less than that of the other two ships. These engines, with six cylinders, were rather too complicated for use in the Navy, and never worked well after the race, although it is notice-

able that in it she was the only one of the three that did not stop owing to some hitch in the machinery. On arriving at Madeira, however, one of her cylinders was found to be cracked, thus adding another to the list. Since then various other kinds of compound engines have been fitted in the Navy, and all, except one, with good economic results, if open to objections on other grounds.

As types of the three principal classes of simple engines now in use in the Navy we may select those of Messrs. Humphry and Tennant, Messrs. Maudslay, and Messrs. Penn.

We will first take that of Messrs. Humphry and Tennant as being the simplest, differing as it does but very little in general design from the old type. The parts exposed to the atmosphere are cased over with sheet-iron bolted to suitable flanges, cast with the cylinder, thus forming a cheap and light form of steam-jacket, and one which may easily be fitted to old unjacketed engines. But this is not a complete jacket, as it still leaves the space covered by the exhaust-passage, and that of no inconsiderable extent, exposed to the cooling action of the condenser; the inequality of the temperature will cause inequality of expansion, and this added to the difference of pressure between the steam in the jacket and that in the exhaust-passage, say about 35lbs., will tend to seriously alter the shape of the cylinder. The cylinder front and cover are both cast hollow and supplied with steam; a boring hole is left in the front, into which the piston-rod stuffing-box is afterwards fitted. The top of the cylinder front is connected with the main bearings by a wrought-iron tie-rod passing through a cast-iron tube, which takes the thrust.

In Messrs. Maudslay's arrangement the jacket is cast with the cylinder, and extends nearly its whole length, but a portion is still left to the cooling action of the condenser. This method entails heavy and expensive castings, and, unless great care is taken, one of the two shells will be probably in a state of tension after casting, and unable to bear the extra strain from sudden shocks when working at high speeds. The three-cylinder engines of this firm have their faces on the top, and must support the whole weight of the treble-ported valves and casings, and in consequence are liable to distortion.

Messrs. Penn's engines may perhaps be best described by an actual example; we will take those of H.M.S. *Hercules*, constructed in 1868. They are of 1,200 nominal H.P.,

fitted with two cylinders, and the usual arrangement of trunks, &c. The inner shell or liner, which forms the working surface for the piston, is cast separately of hard metal, and is merely a cylindrical bush 1½″ thick, with an internal flange at one end 2½″ deep and 1½″ thick. When this bush has been roughly bored, and the flange carefully turned, it is fitted into the exterior shell, and bolted into a carefully-bored recess in the cylinder front. This outer shell has an external diameter of 135½″, with three ribs 2¼″ broad, standing out 1¾″, which supply great lateral stiffness; its thickness is 1¾″, except at the cover end, where it is bored to 131¼″ diameter to a distance of 10″ beyond the cover. When the bush is in its place a rib 7″ from the end, and standing out ½″, fits accurately into this bored part. The space outside this rib between the two shells forms a stuffing-box for the bush, and is filled with several coils of ½-inch galvanised iron wire rope, coated over with red-lead, and kept in place by a ½-inch wrought-iron junk-ring, bolted to the end of the bush; the space inside this rib between the two shells forms the steam-jacket. The bush is forced into place for about one inch by means of long screw bolts through the trunk orifice in the cylinder front acting on wooden beams against the outer end. When screwed in place it is carefully bored to 127 inches diameter, and ground with emery and oil to insure a smooth surface. It can be replaced at any time without removing the cylinder from the ship. A bush fitted in this manner to H.M.S. *Lord Clyde* rested on three ribs, but this is a doubtful addition, as it will then be more easily affected by any distortion of the outer shell. By this form of cylinder the weight of castings is increased, though even then it is not materially greater than that of Messrs. Maudslay, and an extra expense of fitting is incurred; but the compensating advantages have induced its adoption by other makers.

We come now to the most important kind of cylinder yet made for marine engines, for a compound engine with only two cylinders seems the most desirable arrangement for marine purposes. As a specimen of this type we will take those made by Messrs. J. Elder and Co. for the engines of 350 nominal H.P., fitted in the wooden sloop *Tenedos*. Although the diameter of the small cylinder is 56¼″, and that of the large one 90″, still in external appearance they are of the same size. The high-pressure

cylinder is cast with a steam-jacket completely around it and 2½″ from it in the usual manner; around this again is a large annular space called the reservoir, and in some engines the "hot pot," whose outer skin is 15½″ from the steam casing of the cylinder and supported by four radial webs. The steam from the small cylinder exhausts into this reservoir, and is taken from it by the large one, and this reservoir is of such ample size that the difference in pressure caused by admission and emission of steam is scarcely perceptible in the indicator diagrams. The two cylinders are bolted together by flanges fair with the face of the large one, and the space between the jacket of the small and the face of the large one is the valve-case of the latter. The valve of the large cylinder is supported on brackets or ledges cast on the jacket of the small one, and on account of its position between the two is very difficult to get at and examine. The valves are treble-ported, and consequently the faces project some way behind the cylinders. That on which the valve works is cast separately of hard metal and bolted to the cylinder face proper by cone-headed brass screws deeply recessed. The surface has large scores cut in it connecting the screw-holes, so that the steam may act on the slide face, and in a measure relieve the pressure of the valve on the face. The large cylinder is also steam-jacketed completely round, the exhaust passage passing outside the jacket and above the reservoir top. The fronts and covers of these cylinders are also steamed.

The pistons are steamed and the difficulty of getting the condensed water out of them overcome in rather a novel manner. Cast on the back of each piston is a hollow rod, or trunk, passing through stuffing-boxes in the cylinder cover, which is made very deep at the middle to give plenty of bearing surface to these rods. Two parallel tubes work through stuffing-boxes in the end of the back rod, their outer ends being supported on a tripod stand bolted to the cylinder cover. Two legs of this stand are pipes; steam passes through the forward one into the piston and out through the after one, on in the same manner to the after piston, and a pipe is finally carried to the condenser. By opening the cock to the condenser the water is blown out of the pistons, and as but a small quantity of water is condensed in them this need only be done occasionally. A safety-valve loaded to 20lbs. per square inch is fitted to the reser-

voir, as the engines would not work safely with that amount of back pressure. Auxiliary valves are also fitted to both cylinders.

Another specimen of this kind of cylinder arrangement, differing slightly, however, from the one just described, may be here briefly noticed. Messrs. J. Watt and Co. have fitted in the gunboat *Coquette* a compound engine of 60 nominal H.P., in which the face of the large cylinder is on the aft side of the engines instead of between the two cylinders, the reservoir being carried around both, leaving a space of 2″ only about the large one. Both cylinders are cast together and bushed in a similar manner to that adopted by Messrs. Penn, the shells and bushes being both 1″ thick. Even in these small engines auxiliary valves are fitted.

The valve-boxes are very large indeed—in fact, that of the small cylinder stands 8½″ from the slide valve on each side. By thus giving plenty of steam space in the immediate neighbourhood of the valve, wire-drawing in the steam-pipe is reduced. The casings take steam from the valve-box, and the steam from the reservoir enters the low-pressure valve-box on each side of the valve. The small cylinder face only is false in these engines, and is fixed in the same way as that adopted by Messrs. Elder. The valves are supported on rollers fitted on the bottom of the valve-box, and balanced by spiral springs attached to their backs; an equilibrium ring is also fitted, but no vacuum formed within it.

Similar engines have been fitted by Messrs. Rennie to the sloops *Spartan*, *Briton*, and *Thetis*, but not with uniform success. The engines of the *Spartan* have proved an utter failure in every respect, and this might well have been anticipated both for practical and theoretical reasons. When it takes six men six days to open up, and when opened up, the trunk is found to strongly resemble corduroy in its scored appearance, the design cannot be called a success; nor is it an advantage in an engine to be obliged to use the hand-turning gear before a start can be effected when the ship is going end-on to a hulk. In the engines of the *Briton*, however, better success has been achieved. The cylinders are somewhat similar to those of the *Tenedos*, but the steam in the reservoir is re-heated by Cowper's apparatus; this, however, does not give such good results as were anticipated, and will probably be discontinued.

Next to economy, handiness of working should be aimed at, and makers are turning their anxious attention to this. Messrs. Penn

have for many years fitted their well-known auxiliary valves, serving the double purpose of blowing through and working the engine by hand; but other makers, either from professional pride or fear of patent laws, have been slow to follow the lead thus set. The advantage of these valves is clearly seen, and since engines with a high cut-off (and especially two-cylinder compound ones) have come into use, they have become a necessity.

Another improvement worthy of notice, but which is not new, is the method of tightening up the glands by the worm-wheel and toothed-nut arrangement. This kind of improvement is better appreciated by the sea-going engineer than any of those tending to economy. Tightening glands, and especially those of trunks, with the engine working, is at any time a tedious task, but when the ship is rolling it is dangerous as well; nor is it possible even with the greatest care to screw up trunk glands perfectly true with the old arrangements. Now one has only to fit a T-headed box spanner from the platform, and adjust the glands with the greatest precision. This arrangement was fitted years ago by Messrs. Boulton and Watt in the sloop *Cordelia*, 150 nominal H.P., but it is only within the past few years that other makers have adopted it. Messrs. Penn's patent escape valves relieve the cylinders from the continual shock of excessive cushioning, and are simply spindle valves working in boxes placed on the steam passages of the auxiliary valves, and kept on the seatings by their weight and the pressure of steam from the boiler. In consequence of their weight and the difference in area between the top and the bottom of the valve, the pressure in the cylinder has to be a little greater than that in the boiler before they open.

In conclusion, we would again call attention to the fact that there has not yet been found a maker whose cylinder design is infallible when applied to large engines. The radial ribs in the reservoir of the engines of the *Tenedos* are cracked, caused probably by the relative expansion of its outer and inner skin, owing to the difference in temperature. The engines of H.M.S. *Black Prince* had suffered so during her first commission that the forward cylinder was found to be cracked across the face parallel to the axis. It was patched by fitting brass angle pieces in the steam passages, and running a bolt from end to end through the steam and exhaust passages, and was thus rendered fit for service.

H.M.S. *Lord Clyde* had to come home from the Mediterranean with both cylinders cracked, due, it is said, to the working of the ship, the hull of which is of wood. There seems some ground for this assertion too, as, after her cylinders had been re-bored and bushes fitted, the bushes cracked on the trial-trip, and the cylinders had consequently to be taken out and the engines fitted with new ones with the trunk arrangement. Messrs. Penn's plan is undoubtedly good and a step in the right direction, still we hear now that the cylinder of the *Hercules* is cracked and the ship ordered home. More instances might be given, all tending to show that cast iron should not be used alone for the immense cylinders required for war steamers. The only remedy that at present can be foreseen is the more general use of wrought iron or steel. Messrs. Humphrys have made one step in this direction by constructing their jacketings of wrought iron, but this does not altogether answer from the manner in which they are constructed. This firm also contemplated making the pistons of H.M.S. *Monarch* of wrought iron, but sufficiently large plates could not then be obtained.

One would imagine that it would be worth the while of makers to attempt a more extended use of wrought iron in constructing the framing and jackets of cylinders, since cast iron seems to be the proper metal for the working surface, and also the most convenient for the slide face and steam passages. We cannot go on much longer without making some decided alteration in construction, for even cracking cylinders becomes monotonous after a time, and it would be a disgrace to the profession to wait until a coroner's jury had taken the matter in hand. It does not seem such a difficult task to place a cast-iron or even steel bush into a wrought-iron shell, and still by a judicious arrangement maintain all the requisite stiffness. Until something of this kind is done we may expect to hear more of cracked cylinders than will be pleasant, and the delay may be the means of stopping more than one improvement still required to make the engine perfect.

In conclusion, we may remind those who admire and advocate the piston packing ring being pressed against the cylinder by steam, that Messrs. Elder and others having succeeded in steaming the piston, it is only necessary to allow the steam access to the ring to carry out their pet idea.

THE FISHBOURNE FALLACIES.

By William John, Fellow of the School.

Admiral Fishbourne had, as he tells us, "for some years discontinued the consideration of questions of Naval Architecture" when the terrible loss of the *Captain* occurred, and "renewed his interest in his former study." The result is that the Admiral has published three pamphlets,* delivered one lecture at the Royal United Service Institution,† and written several letters to the daily papers. In these publications the author attacks the fundamental principles on which Naval Architects base their calculations, and enunciates for the first time what he calls a "new principle of Naval Architecture." We propose to show that, instead of proving Naval Architects wrong, he only proves that he himself does not understand the subject. We need scarcely tell our readers that Admiral Fishbourne, when speaking of Naval Architects, talks freely about "the wonted absence of comprehension of the subject," "the rabid hostility to a low freeboard," and "the common sense which was so contemptuously thrown aside for a hybrid science;" or that his letters to the press show that he is blind to his errors, even when they are pointed out to him. It will be remembered how, when told in the *Times* a short time ago that he controverted the well-established laws of hydrostatics, he unhesitatingly denied the fact, and boldly "endorsed it" by announcing Mr. Reed as a recent convert to his belief. He has been told over and over again that his conclusions are based upon an inadequate knowledge

* *The Loss of the Captain, illustrating a new principle of Naval Architecture, for the first time enunciated.* By E. Gardiner Fishbourne, C.B., retired Rear-Admiral. London: E. and F. N. Spon. 1870.

Current Fallacies in Naval Architecture. By E. Gardiner Fishbourne, C.B., Rear-Admiral R.N. London: E. and F. N. Spon. 1871.

Current Fallacies in Naval Architecture (second series). By E. Gardiner Fishbourne, C.B., Rear-Admiral R.N. London: E. and F. N. Spon. 1871.

† *On the Causes of the Insufficient Stability of H.M. Late Turret-Ship Captain and of Other Ironclads.*

of the problem with which he attempts to deal; but this only seems to make him embrace his fallacies more closely, and champion them more fiercely. It is of no avail to the Admiral that the unsoundness of his theories is as capable of proof as that the world is round or that the tides are influenced by the moon.

We may, then, before proceeding to expose the fallacies which abound in the writings of Admiral Fishbourne on Naval Architecture, assure our readers that we have not for a moment been betrayed into the weakness of expecting to convince the Admiral himself. Our principal object in writing the present article is to assist those readers of Admiral Fishbourne who, while placing little or no faith in his conclusions, have not sufficient knowledge of the subject to detect his fallacies.

Our chief difficulty, we may mention at starting, is to avoid the confusion which may arise if the technical meaning of some of the words we shall be compelled to use is not clearly defined. This is so because our author makes the most strange and unexpected uses of such terms as *buoyancy*, *stability*, &c.; and many other poor words which are pressed into the service of his pamphlets "would get their *habeas corpus* from any court in Christendom." The following definition of centre of buoyancy is a fair illustration:—

"*The Centre of Buoyancy.*—In works on Naval Architecture this is defined to be the mean centre of the immersed portion of any floating body, but this is not true even in the aggregate. Much of the immersed body may be without buoyancy, and the whole buoyant power may reside in a very small portion of that body. The buoyancy remaining in the immersed body after floating its own weight is equal to the weight of the body above water."

Here the word "buoyancy" is used in a quite different sense from that to which it is applied in works on Naval Architecture. We often read that the "weight of a ship acting downwards is equal and opposite to the buoyancy of the water, acting upwards." The meaning of the term may be pretty well gathered from this one phrase. But since the confusion introduced by Admiral Fishbourne's use of the term is, as it were, the fountain-head from which several of his fallacies spring, we will dwell further upon it.

Let us take a number of blocks of equal size and different specific gravities, but all lighter than water, and immerse them to the same depth. They will all rise to the surface with different velocities. This is not due to any variation in the

buoyant power of the water on the several bodies, which is equal to the weight of water displaced, but to the different weight of the bodies which oppose the lifting action of the water. The unbalanced pressure which imparts upward motion and different velocities in each case is the difference between the buoyant power of the water and the weight of the body.

In scientific writings on Naval Architecture, when the term *buoyancy* is employed it applies to the lifting or the buoyant power of the water. Admiral Fishbourne applies the term *buoyancy* to the excess of the lifting power of the water over the weight of the body, which is a very different matter. The consequence is, that when we find Admiral Fishbourne saying

> "The centre of the immersed body, or figure, termed the centre of gravity of displacement, is rarely ever the centre of buoyancy; and to assume it to be so always can only lead to confusion and danger,"

we know that he gives to the term "centre of buoyancy" a meaning of his own, and one which has no connection whatever with the ordinary use of the term.

According to universal acceptance—our author excepted—the "centre of buoyancy" and "centre of gravity of displacement" are synonymous expressions. The importance of the point so named is due to the fact that the resultant of all the vertical fluid pressures on a ship pass through it. We need not stop to prove this here, because its proof is to be found in every book on hydrostatics. Its comprehension presents no difficulty if the distinction which we have drawn above be borne in mind, and the lifting effort of the water not mixed up with the downward pressure of the weights. The effect of the downward pressure is brought in when we have found the centre of gravity of the ship, because then we know a point in the vertical line through which the resultant of all the weights acts. When the ship heels over from the upright the immersed body alters form, and consequently a new "centre of gravity of displacement" or "centre of buoyancy" is found which determines the position of the line of upward pressure of the water; and this enables us to compute the stability of the ship. Let us now endeavour to follow out Admiral Fishbourne's idea with respect to the *centre of buoyancy*. It may be gathered from his definition of the term, which we have already quoted, as well as from the following passage:—

"The floating power of the parts of a body is in proportion as the specific gravity is less than that of the fluid in which they are floated."

In the first place we should have to divide the ship into innumerable small blocks, find the weight of each, and of an equal volume of water. Then from the immersed portion we should have to select all those which were lighter than water, because, according to our author, they are the only ones which have buoyancy. The amount of buoyancy in each of these blocks would be represented by the excess over the weight of the blocks of that of an equal volume of water.

Admiral Fishbourne's *centre of buoyancy* would then be found by obtaining the resultant of the so-called *buoyancy* of these blocks. So far so good: we have no objection to make to this, except to the novel use of the term *centre of buoyancy*, and the labour involved. We have now to consider a point which seems to have quite escaped Admiral Fishbourne.

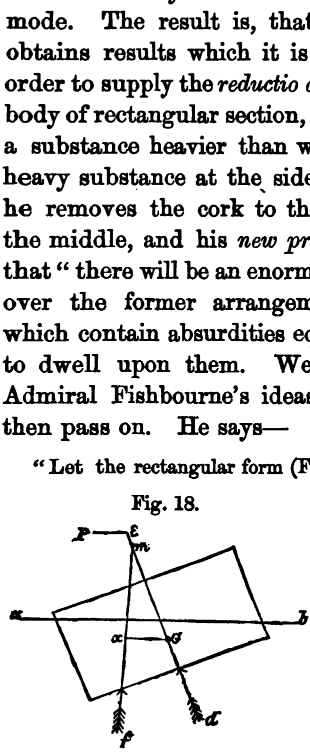
If we are to interpret *buoyancy* in the sense indicated above, how are we to interpret *weight* and *centre of gravity?* Admiral Fishbourne does not see that for *weight* he is compelled to take only those blocks above water in the gross, discard all those immersed blocks which are lighter than water, and take the weights of the immersed blocks which are heavier than water, minus the weight of equal volumes of water; or that he will then get a *centre of gravity* entirely removed from the point to which Naval Architects—and in fact everybody but himself—give that name. It is only upon the condition that Admiral Fishbourne will accept the above interpretation of *weight* and *centre of gravity* that we can possibly accept his interpretation of *buoyancy* and *centre of buoyancy*.

Every one competent to handle a problem in hydrostatics knows that the stability of a floating body obtained by thus dealing consistently with the upward and downward pressures will be exactly the same as that found by the usual simpler mode, if the blocks are taken sufficiently small. To attempt to apply it to a ship, however, would simply be madness. Let any one picture to himself the engine-room of a ship divided up into cubical blocks of, say, a foot each way; and think for a moment of the work involved in finding the weight and centre of gravity of each block. Had there never been a line written on the subject of hydrostatics, such a proposal would not be very

surprising, but to find it advanced in the present day by a British Admiral, who considers it to be his mission to reform the science of Naval Architecture, is something more than astonishing. But Admiral Fishbourne has not even the merit of being able to apply his own principle; because while treating the *buoyancy* and *centre of buoyancy* in the way shown above, he takes the *weight* and *centre of gravity* according to the usual mode. The result is, that he gets into endless confusion, and obtains results which it is only necessary for us to mention in order to supply the *reductio ad absurdum*. For instance, he takes a body of rectangular section, made up of vertical layers of cork, and a substance heavier than water. In the first place he puts the heavy substance at the sides, and the cork in the middle; then he removes the cork to the sides, and the heavier substance to the middle, and his *new principle* leads him to the conclusion that "there will be an enormous increase of stability" in the latter over the former arrangement. Many other cases are given which contain absurdities equally glaring, but we have not space to dwell upon them. We will give one more illustration of Admiral Fishbourne's ideas of stability, viewed statically, and then pass on. He says—

"Let the rectangular form (Fig. 18)" (our figure is an exact copy) "represent a homogeneous floating body inclined by a power at P, and retained there. Let it be supposed f m passes through the centre of buoyancy; in that case m will be the meta-centre, the point where f m, the line of pressure, when inclined, cuts the line d e passing through the middle of the rectangular body and line of support, or of pressure, when upright. *Then the inclining power multiplied by the distance e m will balance the whole weight g, multiplied by g m.*" *

Fig. 18.



This paragraph we may leave without a word of comment, further than to say that it is absolutely devoid of foundation. All our readers know that the weight g multiplied by x G is the moment of statical stability, and that it is balanced by the couple formed by the inclining force, and an equal and opposite force due to the pressure of the water resisting leeway, which acts at

* The italics are our own.

about one-half the immersion of the body below the water surface.

There are at present two kinds of stability recognised as such—namely, *statical* and *dynamical*. The former is pretty generally understood. The second was first discussed and so named by Canon Moseley about 20 years ago. It is simply the amount of *work* done in heeling the ship over to a certain angle. It bears a clear and distinct relation to the *statical stability*; the one being the *force* which can hold a ship at a given angle, and the other the *work* done in heeling her over to that position.

Admiral Fishbourne says there are three kinds of stability—

"1st. That resulting from the form and the vertical position of the weights termed *statical*.

"2nd. That arising from motions vertical and horizontal, termed *dynamical*.

"3rd. That arising from the inertia of weights, resisting motion, or persisting in motion, termed *relative immobility*.

"This last has been lost sight of, and this has given rise to very erroneous views as to the rolling of ships. Their rolling less or more, depends very much on their possessing less or more of this quality. No clear views can exist when these stabilities are confounded or ignored, nor can any attempts to correct rolling be other than empirical, that do not recognise to the full the difference."

Admiral Fishbourne is, of course, ignorant of what has been written by Mr. Froude, Professor Rankine, and several others on the rolling of ships, or he would surely not make such a mistake as to state that the effect of the inertia of ships upon their rolling has been lost sight of. We have indicated above to what use the term dynamical stability is put by Canon Moseley and later writers on Naval Architecture. Does Admiral Fishbourne apply it to the *work* done in heeling the ship? To nothing of the kind. In the discussion at the Royal United Service Institution which followed the paper read by him, he says—

"But there is a dynamic stability, or, if he will have it, hydrodynamic stability, which arises entirely from progressive motion. The faster a ship is going, the greater is that dynamic stability. Every sailor is aware that when a breeze strikes a vessel or boat that has no motion, the first effect is that the vessel inclines very much, as she gathers way she stands up under the pressure of her canvas; that is, just as the dynamic stability increases by her motion, therefore it cannot be ignored." . . . .

"I do not know whether it is in the paper, but as I wrote it originally, I used the expression, 'relative immobility, which resolves itself into dynamic stability.' I used it for clearness, and I believe it is essentially necessary, because these things get confused, and they have latterly got more confused than ever I saw before."

Truly confusion worse confounded. Admiral Fishbourne may some day recognise the fact that the phenomenon which he says every sailor is aware of can be easily explained by means of *dynamical stability*, without any reference to the onward speed of the ship at all! We fear some of our readers would smile were we to recommend Admiral Fishbourne to study the mathematical investigations of Canon Moseley on the subject of stability, yet in the absence of a *Moseley Made Easy*, we scarcely know what alternative there is. We cannot tell; there may yet be some possibility of his threading his way out of the maze of *statical stability, dynamical stability, hydrostatical stability, hydrodynamical stability, "relative immobility which resolves itself into dynamic stability,"* and all the other combinations of that terrible word *stability* in which he has succeeded in entangling himself.

We will not pretend to be able to follow Admiral Fishbourne through his writings on the behaviour of ships among waves. He says, "Mistiness often passes for profundity;" and we infer that the treatment of this part of his subject is intended as an illustration of the maxim. If so, it must certainly be pronounced successful. The only idea which escapes to the surface of a confused sea of words is to the effect that writers on Naval Architecture assume that the force of gravity ceases to act; and in answer to this strange notion, he says—

> "But where is the warrant for the idea that gravity ceases to act even for a second? However men may have differed as to the *value* of gravity, there has been hitherto no doubt as to the *continuance* of its action."

We are afraid this passage is likely to interfere slightly with the continuous gravity of our readers. We will next glance at the effect of the immersion of the lee bilge below the bottom of keel in some ships, a point to which Admiral Fishbourne gives much prominence, and puts forward as a great novelty. It is a matter familiar enough to Naval Architects, and its importance, which is easily calculated, has, we will venture to say, never been underrated by them. But let us see how it is dealt with by Admiral Fishbourne. Taking the case of the *Captain*, inclined at 14°, he estimates the increase of the longitudinal plane due to this cause to be 150 square feet situated 23 feet below the centre of gravity; and the effect of this, tending to upset the ship, he finds to be a pressure of 1,200 *horse-power!* Who ever heard

before of a *pressure* measured by *horse-power?* Do any of our readers know what a pressure of 1,200 horse-power means? We find this in the lecture delivered before the Royal United Service Institution. It cannot be a slip of the pen, or printer's error, because in the same lecture we find, as the result of similar calculations, a "tripping force" given in *horse-power.* The only equal to this in absurdity (for we really can call it nothing else) which we know of is to be found in a letter to the *Standard* (also by Admiral Fishbourne) on the stability of the *Monarch* and *Captain,* which we noticed in our last *Annual.* He there mixes up *statical* and *dynamical stability* in a way which has been happily likened to a man, having a steadily-increasing income, deducting his salary ten years ago from his present salary, and calling the difference the total earnings during that period.

Admiral Fishbourne's craze on the supposed danger of a double bottom, which renders him incapable of understanding, however clearly it is put to him, that the actual vacant space in the ship has no effect on the stability "which is not comprised in the calculations made on the centres of gravity or buoyancy," may be traced directly to his fundamental error on the subject of *buoyancy.* The illustration he draws from the effect of attaching cork to the feet of any one learning to swim may possibly mislead a few casual readers. A little reflection will, however, show that it does not touch the point at issue, which is, whether the effect of the empty spaces in a ship is comprised in the calculations referred to. Moreover, every swimmer knows that a man's body in the water has little or no stability, by the fact that with the least possible effort he can place himself with his back, face, head, or feet upwards, at will. Because cork attached to the feet would destroy this balance, Admiral Fishbourne concludes empty cells in the bottom must capsize a ship. It would be just as pertinent to argue that because a few pounds weight tied to a man's feet would sink him, it would be dangerous to put ballast into a ship.

Another argument used by Admiral Fishbourne in connection with this point is, that if in a ship the weights were all collected at the centre of gravity instead of being distributed, the calculations on the centre of gravity and the centre of buoyancy would remain the same, but the same pressure would no longer move her to the same extent. This, again, is another of the

Admiral's fallacies. A ship under canvas would heel to exactly the same angle whether her weights were concentrated at her centre of gravity or distributed. And exactly the same amount of dynamical *work* would be required to incline her to a given angle. In fact, the *statical* and *dynamical stabilities* would not be affected. We know, of course, that the behaviour of the ship would be very different in the two cases, and that the ship would oscillate in much less time with the weights concentrated than with them distributed.

Our mathematical readers know that this is at once deducible from the laws of hydrostatics, and they need not be told that the effect of the distribution of weights is fully understood and taken account of by Naval Architects in all their calculations upon the actual *rolling motions* of ships. It was scarcely to be expected that Admiral Fishbourne would be able to realise this distinction between the properties of *Stability* and *Rolling Motion*. If any of our untechnical readers, misled by unsound arguments, based upon a flywheel, as to the effect of inertia, are disposed to doubt the above statements, they may very easily satisfy themselves by experiment. A box could be easily fitted with an arrangement for carrying a number of weights, concentrated at its centre or symmetrically distributed round the centre at certain distances. The stability of the box could then be tested under the different conditions of stowage of these weights.

After what we have explained of Admiral Fishbourne's views in the early part of this article, there is nothing surprising in the following passage:—

"All the calculations therefore which have depended on the hypothesis that the centre of gravity of displacement was also the centre of buoyant pressures, must be erroneous and utterly unreliable; the question, then, that suggests itself is, what is the operation of this new view?"

When, however, we find this passage in connection with the following, we are forced to the conclusion that all our previous efforts to unearth the "new view" have been unavailing, and that it now suddenly appears before us in an unexpected garb:—

"It is obvious that whatever the form of the immersed body may be, the pressures must be on the outer skin, and be perpendicular to each part, and the thrust must be resolved into horizontal and vertical forces; these horizontal forces, then, may be disregarded, first, because they balance each other on opposite sides of the ship; and secondly, because they bear no portion of the weight of the ship."

"I suggested the necessity for a method for determining the pressure on ships' bottoms, and for summing them up so as to determine the position or their mean centre at any given time or position of the ship to Mr. Oliver Byrne, and he has investigated the subject mathematically, and is prepared with a formula for the purpose."*

To these paragraphs, which we find in the lecture, we will add the following, which we have culled from one of the pamphlets, into which it seems to have dropped at random to the confusion of the context:—

"Another error was that of making calculations on the hypothesis that the pressures on ships' bottoms were uniform. Thus, the pressure at the first or upper foot square is 64lbs., at 10 feet it is 640lbs., while the pressure at 20 feet depth is nearly 1,280lbs. to a square foot."

We now have the Admiral once more fairly started on a fresh course, this time in tow of Mr. Byrne. It cannot fail to be remarked that we have here an attempt to get at the resultant upward pressures on the ship, quite independent of the empty spaces and varying weights inside. This is, in fact, quite abandoning the newfangled principle of buoyancy which we have previously dealt with. The Admiral would perhaps be surprised to hear that, while thinking he has made some grand discovery, he has simply floated into a channel along which any competent mathematical pilot could steer him to the orthodox theory. Several works on hydrostatics, starting on the hypothesis that the pressure on the outside skin of a floating body varies as the depth below the surface of the fluid, arrive at the conclusion that the resultant upward pressure acts through the centre of gravity of displacement. For want of such a guide we find him still floundering, if we may so speak, among such passages as the following:—

"I said that the centre of gravity of displacement could not be the centre

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* The formula, as given by Mr. Byrne in the discussion on Admiral Fishbourne's lecture at the Royal United Service Institution, is

$$\frac{s}{r}\int\left(1+\frac{dx^2}{dy^2}\right)^{\frac{1}{2}} y^2\, dy = \Sigma\left(\text{PQ}\right)$$

where s is the specific gravity of water, r the radius of curvature of the point (we presume of the ship's bottom), x is measured horizontally and y vertically. It is only necessary, in order to show the worthlessness of this expression, to point out that r occurs in the factor outside the integral sign. Mr. Byrne's other remarks in this discussion tended to show that he has yet to become acquainted with that part of rigid dynamics which treats of the principles of the conservation of motions of translation and rotation.

of buoyant pressures. I now go further and say that these pressures could not be collected at or supposed to pass through a point, for they are all exerted on the skin of a ship, and act with increased intensity below, and their direction is normal to the varied curves of the bottom. The extended lines of these pressures might meet in a vertical plane, but the measure of their vertical action could be obtained only by resolving them into vertical and lateral thrusts. The vertical thrusts might be collected into a perpendicular to the earth, but having their origin in a point in the lowest part of the skin of the vessel, of every section, but not in a point in the vessel above the bottom. Now these pressures have their moments, according to their distances from the water line, and they act with the power of the varying specific gravities of the body on which they operate, and are effective for good or evil in proportion as the moments of the parts opposed to them are in excess or in deficiency of their moments."

And complaisantly indulging in such—shall we say twaddle? —as the following:—

"Treating the pressures of the water as being always on the outer skin of the vessel, will lead to a correct determination of the position of masts, the lateral and vertical moments of sail, and to an approximate measure of the dynamic stability from horizontal motions, if not also to a determination of the direct resistances."

We have by no means exhausted the catalogue of Admiral Fishbourne's fallacies, and it would be useless to attempt to do so in the present article, because, to say the truth, it would involve quoting the whole of his writings before us, comprising nearly a hundred pages. Some of the worst fallacies we are compelled to pass over, because to deal with them fully would take up considerable space, and require the use of several diagrams. Moreover, it would serve no useful purpose, as we have sufficiently shown that on the whole subject, from the simplest elements upwards, he is—not to put too fine a point upon it—hopelessly bewildered. Of passages like the following we could quote more than enough:—

"Yet it has been recommended to reduce the stability of the *Great Eastern* by one-half, which would leave her without any." . . . . . .

"When the helm is put over to turn the ship round, she heels over proportionably to her deficiency of initial stability and the power that ought to have been employed in giving motion or liviug power to the sides and ends is absorbed in producing inclination, and so that when her way is lost or nearly so, and the power of the helm small, these have no momentum to carry her round over the *dead-point.*" . . . . . .

"As to turrets or broadsides I give no opinion, as I have not studied the subject; it is as an architectural question that has been viewed by controversialists, as the shields were by the combatants of old, each looked from his own stand-point, and pronounced it black or white, that I wish to deal with it, because in the contention the public suffers, and *sailors perish.*"

But why continue? Small pleasure does it afford to hold up any one to ridicule, even when to quote him is sufficient for that purpose. And most unpleasant is it to have to discredit the writings of any member of that noble profession upon which England depends for her maritime supremacy. If we have been severe upon Admiral Fishbourne, we have most assuredly not been unfair to him; and we think it a duty to expose unsparingly the fallacies of any one who scatters broad-cast such statements as the following, on a subject which he does not, and probably never will, understand:—

"Many ships—yes many—in the Navy appear unsafe." . . . . . .

"When another ship or two founder and drown their crews, we shall awake to the fact that this latter is not science." . . . . . .

"At present, on these points Chaos reigns triumphant in the constructive department of our Navy." . . . . . .

"We have been continually victimised by this narrowness, a hobby always being ridden to the great injury of the Navy, and at a senseless cost to the country; the extravagant and dangerous things that have been done by them no sailor would have been a party to."

It is simply laughable, when we know the character of Admiral Fishbourne's writings, to find him cast into the melting mood when charged with throwing contempt upon Naval Architecture, and exclaiming—

"My whole paper is a contradiction to that. My whole life is a contradiction to it. From the earliest days of my boyhood I have thought upon the subject. Am I, then, likely to throw contempt upon Naval Architecture?"

Or to find him, with the impartial and childlike simplicity of a votary of science, saying meekly:—

"This whole question is so important that I will sacrifice my time, and come at gentlemen's beck and call to consider their facts, their statements, and proofs. What more can I do?"

So we could go on quoting (as Admiral Fishbourne will probably go on writing) passage after passage, which display the strangest mixtures of prejudice, bathos, and incoherence, which it has ever been our lot to meet with. But in spite of the ludicrous nature of the blunders these pamphlets contain, which makes the first reading of them very amusing, on second perusal they leave an uncomfortable feeling of doubt in the mind. The question is naturally forced upon us whether the causes of their appearance must be sought for exclusively among the records of psychologists, or whether much is not due to the neglect of enforcing such an early scientific training on our naval officers as to render exhibitions of this kind by an Admiral impossible.

THE ROLLING OF SHIPS.

BY P. WATTS, FELLOW OF THE SCHOOL.

AMONG the many subjects relative to the designing of ships which have occupied the attention of scientific men of late years, there is none more important or more difficult than the rolling of ships at sea, involving, as it does, elements in their construction which may not be neglected with impunity. Hitherto, so far as practical shipbuilders are concerned, this matter has scarcely, if at all, been considered, except in their endeavour to provide sufficiently for the strains which the structure must undergo when subject to the action of the wind and waves; but there are other considerations in connection with the subject which are almost as important, on which much of the ship's safety depends, and these are generally neglected. Many a well-built vessel that has foundered at sea would probably have had a successful career for years had she been so designed as to comply with theoretical requirements, and thus it should be the earnest endeavour of all concerned to perfect, as far as possible, our present knowledge of the subject, and put in practice what is already known. To this end a succinct account of the results at present obtained may possibly be of service.

In dealing with the subject we shall first take the most simple case—that of a ship rolling in still water—neglecting the resistance of the water, and supposing the vessel to be rolling so that she constantly displaces a quantity of water equal to her weight. Not that these limitations are inconsiderable, but because by allowing them we are enabled to make the following construction, which will materially assist our conception of how the vessel rolls.

Let Fig. 1 represent the ship rolling in the direction indicated by the arrow, W W being the water line in her present position. We suppose her to have been heeled over to some

inclination such as that indicated by the position of the water line *w w*, and then allowed to oscillate freely under the action of her weight and the upward pressure of the water alone. Let G be her centre of gravity, and B B′ the centres of buoyancy corresponding to the upright and inclined positions respectively, so that M is the metacentre—*i.e.*, the point where B M, the vertical through B′, intersects the original vertical through B and G—the angle of inclination being small. Then, as is well known, M G is a measure of the *righting force*—*i.e.*, of the effort exerted to turn the ship towards the upright position. It is this *righting force* which makes the ship oscillate: as she rolls from the extreme position on one side the *righting force* gradually diminishes, and in the upright position vanishes, but in rolling through this angle it accumulates an amount of work which is just sufficient to carry the vessel to the same inclination on the other side. This is evident from the fact that the *dynamical stability* up to an equal angle of inclination on each side is the same—for the work accumulated by the righting couple, as the vessel passes from the extreme position to the upright, is the dynamical stability corresponding to the angle of heel, and, of course, this is just the work which is required to incline her to the same angle on the other side. The motion of the ship oscillating thus about her upright position is analogous to that of a pendulum, the principal difference being that whereas the bob of a pendulum turns about a fixed point—the point of suspension—the axis about which the vessel rolls *moves* through a certain path dependent on the position of the centre of gravity, and on the figure of the vessel. We proceed to trace this path.

Let us imagine a surface which will constantly touch the plane of the water—supposing it to be continued right through the vessel—as she rolls from side to side; this surface, indicated by *abc*, is called the *surface of flotation.*

Now, let us suppose this surface of flotation together with the surface of the water to become rigid surfaces without friction, conceiving the former to be capable of rolling and sliding upon the latter without being interfered with by the material parts of the vessel, except in so far as it will be influenced by the forces of weight and buoyancy acting vertically through the centres of gravity and buoyancy respectively. The motion of

the ship under these circumstances, supported by its surface of flotation resting upon the rigid but perfectly smooth water plane, will in all respects be the same (restricted as we have supposed) as if it rolled in the water uninfluenced by these imaginary surfaces. The problem is thus reduced to that of the motion of a solid body, without weight and of fair external surface, upon a smooth horizontal plane acted upon by certain forces.

The instantaneous axis* about which a body is turning is known when the motions of any two fixed points in the body are known. The forces of weight and buoyancy being wholly vertical, the centre of gravity must move in a vertical line; therefore if G be the centre of gravity, the instantaneous axis must be in the horizontal line G O. Also, as the surface of flotation slides upon the plane of the water the instantaneous direction of H, its point of contact, must be along the plane of the water, hence the instantaneous axis must lie in H O, and therefore it is the point O where G O and H O intersect. From this we see (following out the process through the entire motion) that the locus of the instantaneous axis as the ship rolls from side to side will be some such curve as that indicated by the dotted line O′GO passing through the centre of gravity and turned up towards its extremities. It may be readily shown from the dynamical equation of a ship rolling under these circumstances, that the time of her roll or oscillation is practically the same as that of a *simple pendulum* whose length is equal to the square of her radius of gyration divided by the height of the metacentre above the centre of gravity.

This kind of imaginary rolling (water set in motion, &c., being neglected) is called *unresisted rolling in still water*. The time of a roll is usually measured by the time it takes for the ship to pass the upright position twice moving in the same direction; it corresponds to what is called a double oscillation in a pendulum.

If we remove the limitations we have made, the case is very

* This is the axis about which a body may be supposed to turn through a very small angle, considering its motion at any particular instant. The construction of the instantaneous axis given above was pointed out by Canon Moseley.

materially altered. The keel and sharp parts of the floor and the bilge keels (if the ship has any) tend to set in motion large volumes of water, and the resistance thus caused has a steadying effect on the vessel, diminishing the extent of rolling and lengthening the periodic time. Professor Rankine has shown that by these causes the extent of rolling is diminished nearly in geometrical progression at a rate increasing with the amount of resistance offered, and diminishing as the moment of inertia is increased; and that the time of rolling is increased in the same way as if the radius of gyration were increased in a certain ratio depending directly on the amount of resistance exerted, and inversely on the height of the metacentre above the centre of gravity.

As regards the instantaneous axis, in passing the upright position she will be generally turning about a point a small distance below the centre of gravity, and the locus of the instantaneous axis will probably be considerably turned down and looped towards its extremities, rather than turned up as shown in the figure.

By bearing in mind the locus traced by the instantaneous axis as the ship rolls, we are enabled to form a good idea of the lurching or lolling motion she undergoes.

The consideration of the rolling of ships in still water is of considerable importance, as it depends upon elements in their design which largely determine their rolling properties among waves. In fact, as we shall presently show, when their time of *unresisted rolling in still water* is known, their behaviour among waves so far as rolling is concerned may be fairly estimated. We shall now pass on to consider the rolling of ships among waves, and in doing so we shall first examine somewhat the nature and character of waves, in order to more readily understand the action of the hydrodynamic forces they exert.

We shall deal with *deep water waves*, the depth being such as not to interfere with the form of the waves, and shall consider the disturbing cause—the wind—to have subsided, and the ocean to be traversed by uniform waves of the same size running parallel to one another. It is only the *form* of such waves that travels. Theory and observation agree in showing that every particle of water affected by these waves uniformly describes a circle about a point rather above its still water position, as each

Fig. 1.

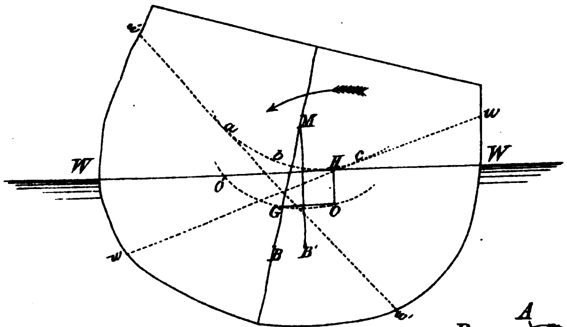
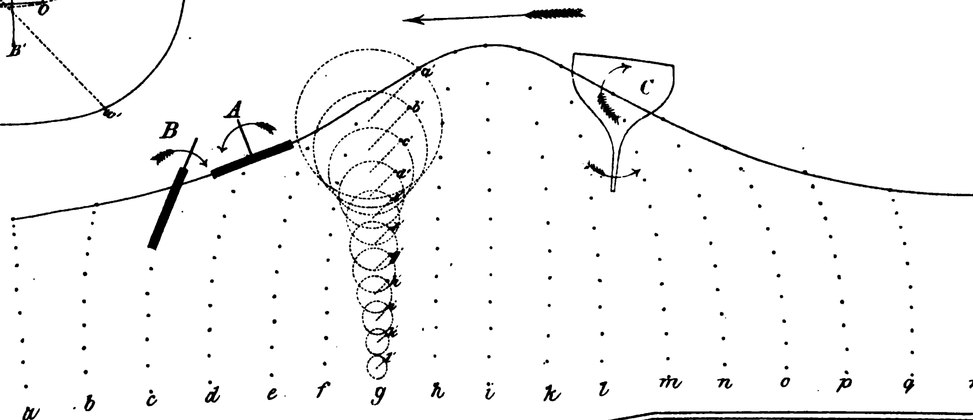


Fig. 2.



successive undulation passes it, and we may consider that it is this motion of the water, as a body, which gives the waves their form and speed. The length of a wave is the distance between two successive hollows or crests, measured in the direction in which the wave travels; the height of a wave is the vertical distance between the hollow and crest; and the time or period of oscillation is the time it takes to traverse its whole length.

We will consider the motion of a particle of water on the surface as it is traversed by a wave—commencing from the instant when it is in the middle of the hollow between two crests. Suppose the wave to be passing from right to left. As it moves towards the particle, the latter rises upon its surface, and at the same time moves slowly towards the crest from left to right, this second movement, however, only continuing while the waves run through rather more than half the distance between the hollow and the crest, during which time the particle describes the lower right-hand quadrant of the circle. It then begins to move backwards from right to left with the crest, at the same time being raised by the surface of the wave, describing the upper right-hand quadrant of the circle, which it will have completed when the top of the crest overtakes it. It will then be immediately over the point from which it started. As the wave passes on, it continues moving with it in direction, and at the same time descends on the back slope of the wave, describing the upper left-hand quadrant of the circle; it then moves slowly backwards from the crest, continuing down the back slope of the wave through the lower left-hand quadrant, arriving finally at the instant the wave passes it at the same point from which it started, having described a circle of the same diameter as the height of the wave.* The whole of the surface particles will, of course, be affected in exactly the same way. With regard to the motion of the water below the surface during the passage of a wave, every particle describes a circle in a manner similar to that of the surface particles, but with this difference—the radii are smaller, and decrease in a certain ratio which depends on the depth from the surface.

Let Fig. 2 represent a wave such as we are describing. The circles a', b', c', &c., are paths described by a number of

* It is evident that the profile of such waves will be of trochoidal form.

particles which, if the water were at rest, would be in a vertical line and equidistant from each other. The motion undergone by this line of particles may be readily followed by keeping in mind how each particle traverses its orbit as the wave passes. The dots in the lines *a b c d*, &c., indicate the positions occupied by these particles as they are passed by the corresponding parts of the wave. At the middle of a hollow they are in a vertical line, and are depressed from the still water position, being closer together the nearer they are to the surface. When the crest of the wave passes they are again in a vertical line, but they are raised above their still water position, being further apart the nearer they are to the surface. In the intermediate positions, between the hollow and crest, the line they are in bends towards the crest in such a way that its inclination to the vertical at the top is at each instant practically equal to the slope of the wave at that point—that is, to the inclination of the surface of the wave to the horizon. The still water positions corresponding to the lines *a b c*, &c., being at equal distances apart, the shapes inclosed between these lines and the surface of the wave indicate the change in configuration undergone by a block of water as the wave passes. It is very important to observe this change, as the motion of any body, such as a ship, floating on the wave, must naturally be largely influenced by it, the water tending of course to carry the body with it.

Suppose a ship to be floating broadside-on among waves such as we have described; where they are long, compared with the draught of water of the ship, we may consider that to the depth of her draught below the surface the particles of water practically revolve in circles of equal radii. Neglecting for the present the action of the water upon the ship, due to the change of configuration it undergoes as the wave passes, the forces acting upon her are exactly the same as those which would act upon her in still water, combined in each case with the centrifugal force with which the particles of water at the surface are revolving—for the pressure exerted by the water upon any point of the surface of the ship is the resultant of the pressure which would act on this point in still water, combined with the centrifugal force with which the particles of water are rotating, and so on over the whole of her immersed surface. Hence the resultant

pressure of the water upon the vessel is the resultant effect of the pressure which would act on her in still water, combined with the centrifugal force, and it acts (by a well-known principle in hydrodynamics) through the centre of buoyancy perpendicular to the wave at this part. Also the centre of gravity of ship describes a circle, as each wave passes, of practically the same diameter as the particles of water in contact with her surface, so that she exerts an equal and opposite pressure upon the water. Hence we have nearly the same forces acting on the ship as there would be in still water, only that they act in a direction constantly normal to the wave surface, and she will have a tendency to keep normal to the wave surface, which will nearly equal her tendency to keep upright in still water,* and if she be inclined from this normal, the same couple, practically, tends to restore her to it as in still water would tend to restore her to the upright if she were inclined from it by the same amount. Ordinary ships will not, however, keep normal to the wave surface. We have already referred to one cause tending to prevent this†—viz., the change in the configuration undergone by the water relatively to the wave surface. This is modified by the ship's inertia, which tends to make her perform oscillations about the normal to the wave surface in the same periodic time as in still water. The action of the waves, however, is such that the vessel is compelled to perform these oscillations in the same time as the waves. Thus we may regard the rolling of a ship among waves as made up of the motion she would have supposing she always kept normal to the wave surface, combined with the oscillation she performs about the normal to the wave.‡ The tendency to keep the ship normal to the wave surface is called *stiffness*, while the tendency to keep her vertical is called *steadiness*.

With the supposition we have made, neglecting also the resistance of the water, the exact differential equation of the motion of the ship may be written down, and though it has not yet been solved, a very approximate equation has, and from it we gather

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* This tendency was pointed out by Mr. Froude, in 1861. It was the first great step towards our present knowledge on the rolling of ships.

† At sea there are many causes tending to do this; such as variations in the force and direction of the wind, irregularity in the shape of the waves, &c.

‡ In dealing with the safety of ships among waves, their extreme inclination to this normal must be taken.

the following results, which are verified by experience:—If the radius of gyration of the ship and the height of the metacentre be such that her time of *unresisted rolling in still water* is the same as the time of the waves, each roll of the ship as she is passed by successive waves will be increased in amplitude by a constant amount varying directly as the maximum slope of the wave, so that but for the friction of the surface, and the resistance to motion offered by the keels, sharp parts of the floor, &c., the ship must eventually roll completely over, no matter to what angle she may possess stability, or how small the waves may be; and the more nearly her time of unresisted rolling in still water approximates to the time of the waves, the more nearly will this result be approached. From this we infer that in designing it is desirable to arrange so that the ship's time of unresisted rolling in still water may be as long as possible, in order that she may not be likely often to meet with waves of her own period.

We have already, in dealing with ships rolling in still water, explained the nature of the resistance to rolling offered by the water, arising from the fact that part of the force tending to make the ship roll is expended in setting in motion large volumes of water through the medium of her keels, skin resistances, &c. This is equally true in the case of the ship among waves, besides which the motion of the water relatively to the wave surface may not be neglected, the tendency of the ship to follow this motion offering considerable resistance to her rolling. The nature of this action is very apparent from what we have said of the motion of vertical columns of water during the passing of a wave.

Let us consider the two following extreme cases:—1st. The case of a flat board, such as A, floating on the surface of the water; this we may consider a form of unlimited stability—it follows the wave surface. 2ndly. That of a thin weightless board, B, of no stability, floating so that it would be vertical if the water were at rest—it follows the motion of the particles of water of the originally vertical columns, and therefore, as we have seen, its inclination to the perpendicular at any instant is approximately the same as the slope of the wave at that point, and therefore the same as the inclination of A to the horizontal, supposing A and B to occupy about

the same position on the wave. We observe that the wave surface as it moves along tends to turn A in the direction indicated by the small arrow above it, but the originally vertical column of water in which B floats tends to turn B in the opposite direction, so that these two actions are of a conflicting character; and if we were to secure B to the under side of A perpendicular to it, they would evidently undergo an intermediate motion. This is just the case with a ship—the action of the waves upon that part of the ship between wind and water is opposed to their action upon the keel and sharp parts of the floor; the combined effect being a tendency on the part of the waves to make her take an intermediate course, as shown at C.

It would be dangerous to attempt to make a ship roll like the flat board on the surface of large waves, as might be done approximately, by making her stability very great, concentrating the weights at the centre of gravity, and increasing her breadth, for by so doing we should only reduce her *time of unresisted rolling* in still water so that she would be frequently falling in with smaller waves among which she would roll very considerably. A ship may be made to roll like the board in the second case, *with* the originally vertical particles of water, by making her periodic time of unresisted rolling in still water, divided by the period of the waves, equal to $\sqrt{2}$. In this case the ship is upright at the middle of the hollow between two waves, and on the top of the crest, and there would be a like result if she were to roll like the flat board on the surface of the water. In both of these cases the angle through which she rolls is evidently the same as the maximum slope of the wave.

If her periodic time of unresisted rolling in still water be *less* than the $\sqrt{2}$, the upright positions occur before the arrival of the hollows and crests, and if greater, after the arrival of the hollows and crests; in the first case the maximum angle of heel of the ship is greater than a certain quantity—the height of the wave divided by the diameter of a circle whose circumference is equal to the length of the wave—but in the second case it is less than this quantity.

Thus on the whole we see it is desirable to lengthen the time of unresisted rolling in still water as much as possible. This, as we have already pointed out, may be done by lengthening

the ship's radius of gyration and decreasing the distance between the centre of gravity and metacentre. The radius of gyration may be increased by winging out the weights—that is, by placing them as near the sides of the ship as possible without lowering them. Considerable facility is afforded for doing this in a war vessel in the disposition of the armour and guns, by placing them well out on the sides as far from the middle of the ship as possible. The distance between the centre of gravity and the metacentre may be diminished by raising the centre of gravity—that is, by raising the weights bodily. This we may do only to a very limited extent, for the tendency which the ship exerts to keep upright, and to return to the upright when inclined, depends both in amount and in the extent of the angle of inclination on the lowness of the position of the centre of gravity.

We have supposed the vessel to be rolling broadside-on to the waves; if she be in motion and her course be inclined to the direction traversed by the waves instead of perpendicular to it, the apparent time of the waves relatively to the ship must be taken in dealing with the question of her rolling—that is, the time that elapses between the passing of two successive crests or hollows. Thus the effective wave period may be varied very considerably by changes in the direction and speed of the vessel.

Our present knowledge of the rolling of ships among waves is largely due to the labours of several of the members of the Institution of Naval Architects, and in dealing with the subject our object has been to condense the results of their investigations and make them intelligible to the general reader. At the first meeting of this institution, March, 1860, Dr. Woolley, who read a paper "On the Present State of the Mathematical Theory of Naval Architecture," expressed his regret that so little reliable information was possessed on this subject. Since that time, however, it has been so thoroughly dealt with, at least so far as theory is concerned, that it would seem that little more can be done except in the way of experimental investigation.

ON CURVES OF BUOYANCY AND METACENTRE FOR VERTICAL DISPLACEMENTS.

BY GEORGE STANBURY, FELLOW OF THE SCHOOL.

THE principles involved in calculating the positions of the centre of buoyancy and metacentre for any given draught of a vessel are so well known that there scarcely seems a necessity to state them here. But for the sake of a clear understanding of the subject of this paper, perhaps it will not be out of place to define the terms centre of buoyancy and metacentre.

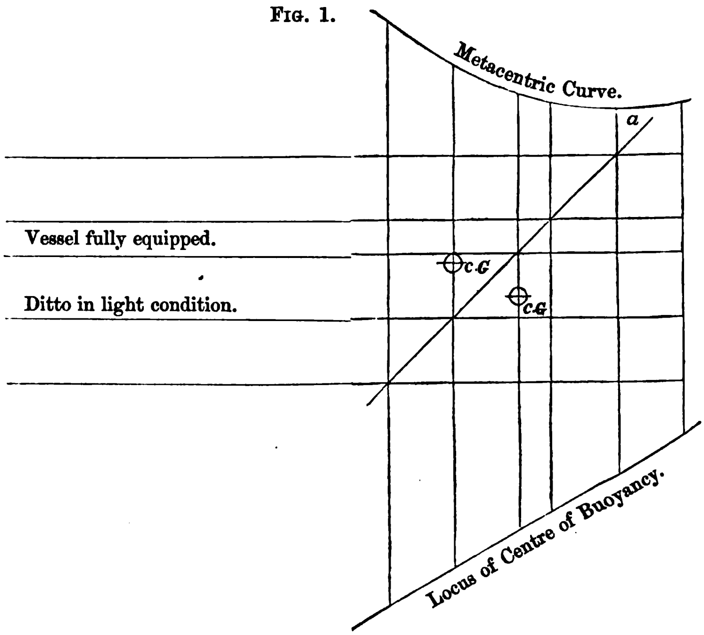
The centre of buoyancy of any floating vessel is the centre of gravity of the fluid displaced by that vessel.

With respect to the metacentre, we shall simplify matters if we confine our attention to what is meant by the transverse metacentre for the upright position of equilibrium, since that is what we shall be concerned with in what follows. A vertical line drawn through the centre of buoyancy found for the upright position of a vessel will intersect the vertical drawn through the centre of buoyancy of the ship when she has received an indefinitely small angular motion about a longitudinal axis. The point of intersection of the two vertical lines is called the metacentre for the draught at which the vessel is supposed to be floating. A more general definition, as applied to finite angles of heel, is to be found in the paper on Calculations of Stability, by Messrs. White and John, contributed to the *Transactions of the Institution of Naval Architects* for 1871. Works on hydrostatics show that, to find the height of the metacentre above the centre of buoyancy, we must divide the moment of inertia of the plane of flotation about a longitudinal middle line by the volume of displacement. Hence for different parallel draughts of water we shall in general arrive at different heights of metacentre above the centre of buoyancy. Under the title of this paper it is proposed to consider some of the features of curves showing the relative positions of the centre of buoyancy and metacentre

to each other as well as to their respective water lines, for parallel planes of flotation. We wish it to be clearly understood, that in what follows we are never dealing with any heeled positions of the vessel, but only with upright positions.

The manner in which these curves are represented graphically was first published by Mr. Barnes, in a paper read at the Institution of Naval Architects in 1860, and an example taken from the calculation for an actual ship is here given. By re-

FIG. 1.



ferring to the diagram we see that the horizontal lines represent parallel mean draughts of water, set apart according to scale. A line is drawn at an angle of 45° in a convenient position across the horizontal lines, and through each intersection a vertical line is drawn. The vertical lines will then be at the same distances apart as the corresponding horizontal lines, and will represent the various draughts of water, measuring horizontally. When the depth of the centre of buoyancy below its corresponding water line is known, we can set it off (to the scale previously used for the water lines) along the verti-

cal, and from the horizontal line corresponding to the draught taken in the calculation. By repeating the process we shall obtain a series of points which, when joined, form what is called the locus of centre of buoyancy. The height of the metacentre above centre of buoyancy when found is set off above the locus of centre of buoyancy in a similar manner, and then the diagram is complete so far as the form of the ship is directly concerned.

The main object in making such a diagram is to present clearly to the mind in what position the centre of gravity of hull and weights on board stands with respect to the metacentre. For the first element of stability of a given ship is the distance between the centre of gravity and metacentre, or, as it is called, the "metacentric height." The principles and method employed to find the position of the centre of gravity of a ship afloat have been fully discussed by many writers on Naval Architecture, and we do not consider it necessary to say anything on that subject here. Suppose, then, that the positions of the centres of gravity for various probable dispositions of the weights on board are known. If we set off on our diagram vertical and horizontal lines to correspond with the known draught when certain weights are on board, we can mark with a scale where the centre of gravity will be on the vertical line, and the metacentric height is then easily measured. From this it follows that it is necessary to calculate the height of metacentre and position of centre of buoyancy for a draught a little distance beyond the plane of flotation the ship will have when fully equipped, as well as for a draught at some distance below the floating line for the lightest condition. The character of the metacentric curve for a ship between the limits of load and light draughts is sometimes such as to render it necessary, for exactness in measuring the metacentric height, to calculate the positions of the centre of buoyancy and metacentre for draughts 3 or 4 feet above and below the load and light water lines.

When a ship has her full complement of weights on board, the centre of gravity of the whole mass is in general nearer the keel by about 1 foot than when she is in what is called the light condition—that is, when her stores, coals, &c., are consumed. If in any case, then, the metacentric curve between the load and light lines does not rise in a vertical direction through

as great a distance as the centre of gravity has done, it is clear that the "metacentric height" (or what is directly proportional to that height—viz., the initial stability) will be greater when the vessel is fully laden than when she is in her light condition. In most vessels this decrease of initial stability* actually takes place as the stores, &c., are consumed, and it does appear desirable that a rapidly ascending metacentric curve in passing from the load to light lines should be aimed at to some extent by the designer.

The primary object in writing this paper has been to attempt to give some results, connected with these curves of buoyancy and metacentre, which have been deduced from prismatic ships with symmetrical transverse sections, that we may to some extent be able to judge *à priori* what description of metacentric curve we shall get from the lines of any ordinary-shaped vessel. Or when the curves have been obtained by means of long calculations, some of their features may be tested by the principles to be given hereafter.

Let us first consider the curves of centre of buoyancy for various transverse sections of prismatic ships.

Before examining any particular cases it will be well to examine what connection exists between any ordinary vessel with the extremities fined off, and a prismatic ship (or ship of constant transverse section) with the mean section† of the fined ship for its constant section. It is the general practice to construct what is called a curve or scale of "tons per inch immersion" in connection with the calculation of the displacement of a vessel. Now by a simple arithmetical process we can find the ordinates of the mean section from the curve of tons per inch immersion. Having obtained the mean section by this process, it is easily seen from the principle of moments that the height of the centre of buoyancy of the vessel with fined ends will be the same as the height of the centre of gravity of this mean section, or still further, the same as the height of the centre of gravity

* By initial stability we mean the power of resistance which a ship offers to being heeled from the upright position.

† The area of the mean section of any vessel is the mean of the areas of all the transverse sections. It is graphically constructed by setting off ordinates square to a vertical line, corresponding to different parallel draughts of water. The half area of each water plane divided by length of ship is the length of ordinate to be set off on each side of the middle line.

of the scale of tons per inch immersion, the draught being the same in the three cases. It therefore follows that the locus of centre of buoyancy we arrive at for a prismatic ship, whose section is the same as the mean section of a certain ship, will also be the exact curve for the latter.

The most general form of mean section occurs where the relation between the draught and half breadth of section at any position is expressed by $y = f(x)$ – where y is any half breadth, x the draught corresponding, and f expresses any function of x. The height of the centre of buoyancy from the lower side of keel will be found from the general expression—

$$\bar{x} = \frac{\int xydx}{\int ydx}$$

We shall now assume some simple relations between the x and y of a few mean sections, and then find the heights of the centre of buoyancy for parallel water lines. The draughts x are supposed to be set off along a horizontal axis, and the corresponding heights of the centres of buoyancy z we will imagine set up vertically from the horizontal axis. This method of construction really amounts to what is done in the diagram already described.

The simplest case of mean section is a *rectangle*. Now the centre of buoyancy in such a section is always at a height equal to half the draught measuring from the base or keel. The locus is consequently defined by

$$z = \frac{x}{2}$$

When this is referred to the axes of co-ordinates that we have chosen, we get a straight line, passing through the origin and making an angle $\tan^{-1}\frac{1}{2}$ with the axis of x. This result is independent of the breadth of the section, and is consequently the same for all rectangular sections.

A triangle with the vertex down is another simple case. Treated like the above the locus of the centre of buoyancy is seen to be a straight line passing through the origin as before, but making an angle $\tan^{-1}\frac{2}{3}$ with the axis of x. This result, too, is the same for all triangular sections.

For the third case we will take a trapezium for a mean section; the base to be parallel to the water lines, and of breadth a. The sides are "flared out," each making an angle

α (> 90°) with the vertical. The equation to the locus is found to be

$$z = \frac{x\,(3\,a - 4\,x\tan\alpha)}{6\,(a - x\tan\alpha)}$$

A hyperbola whose centre is at the point $\left(\frac{a}{\tan\alpha}, \frac{5}{6\tan\alpha}\right)$. Now $\tan\alpha$ being negative, the centre will be in the third quadrant. The directions of the principal diameters of the hyperbola are found from the equation $\tan 2\,\theta = -\frac{3}{2}$, a result which is independent of α and a. The branch of the hyperbola forming the curve of centre of buoyancy is *convex* to the axis of x, and the angle between the tangent to the curve at any point and the axis of x is always less than 90°.

When α is less than 90°, as in the case of "tumble home" sides, the above equation again represents the curve of buoyancy. Recollecting that $\tan\alpha$ is now positive, the curve is found to be *concave* to the axis of x.

Next let the mean section be "wall-sided," or rectangular from the light draught to all deeper ones, while below the light draught the section is of any form. Let a be the breadth of the section at the light line, — C the area of the section, and d depth of its centre of buoyancy, below the light line. The equation to the locus is

$$z = \frac{ax^2 - 2\,C\,d}{2\,(ax + C)}$$

supposing the draughts x measured from the light line. The curve of buoyancy is now a branch of a hyperbola, the centre being determined by the co-ordinates $\left(-\frac{C}{a}, -\frac{C}{a}\right)$. The transverse axis of the hyperbola makes an angle $\frac{1}{2}\tan^{-1}(-2)$ with the axis of x. The curve will be *concave* to the axis of x, with the condition that $2\,ad > C$. This condition exists in all ordinary-shaped vessels.

The above results agree with those found by calculating the positions of centres of buoyancy of an actual ship whose mean section is of the form last considered. Between the light and load lines the locus is practically a straight line inclined at an angle of 30° to the horizon, while below the light draught the curvature of the locus slightly increases, the curve being *concave* to the axis of x.

A more general case than either of the foregoing is a mean section whose sides, above the light draught, are straight lines, "flared out," while below that draught the section is of any form. Let the breadth at the light draught be a, and let the sides each make an angle α with the vertical. The letters C and d stand for the same quantities as in the previous case, and draughts x are measured up from the light line as in that case. The locus will be

$$z = \frac{3\,ax^2 - 4\,x^3 \tan\alpha - 6\,C\,d}{6\,(ax - x^2 \tan\alpha + C)}$$

—an equation of the third degree. The tangent to the curve at any point always makes an angle less than 90° with the axis of x, since $\tan\alpha$ is negative. The general conditions for concavity or convexity are very complex in this case, but the values of the constants obtained from actual ships when substituted, show the curve to be slightly *concave* down at the light draught, to be practically straight for draughts near the load line, and for some feet beyond. Above this the curve is gradually more and more *convex*. By varying the values of a, C and α, we can lessen the length of the straight part of the curve mentioned above, and cause the convexity to be more decided at smaller draughts.

The want of space compels us to omit many of the details required to complete the tracing of these curves, but we may remark here, that in practice the mean sections of most vessels are straight above the light line, the sides being "flared out" or inclined to the vertical, as in the last example.

It may be as well to add, before proceeding to consider the metacentric curves, that the straight portion of the locus of centre of buoyancy alluded to is, for most ships, inclined to the horizontal axis, at angles varying between 28° and 30°*, the higher limit being by far the most frequent in practice.

The algebraic expressions for the height of metacentre above the centre of buoyancy involve more complicated equations than the curves of buoyancy have been found to, and we are not able to obtain practical deductions for the former so readily as for the latter. Prismatic ships with simple transversal sections will be again used in discussing the metacentric

* These angles fall between the angles of inclination of the buoyancy curves found for the square and triangular sections—viz.: 26° 27′ and 33° 19′ respectively.

curves. With a ship of the ordinary form, the moment of inertia of any water line is considerably greater than the moment of inertia of the corresponding water line of the prismatic ship with the mean section of the same vessel. Hence the height of metacentre above the centre of buoyancy for the vessel with fined extremities will be greater than that for the prismatic ship—the water line in the two cases being the same. This will, of course, interfere with the results obtained for prismatic ships being applied directly to actual ships. But by comparing the curves calculated for actual ships with those obtained for different mean sections, the results in the latter case, it is found, serve as indications of the former. The relations between the moments of inertia of the corresponding water lines in the two cases evidently depend upon the degrees of fineness given to the water lines of the one ship, and this degree varies in a complicated manner in passing from one water line to a parallel one. However, we will now consider some cases of prismatic ships, and point out where the results obtained agree with the metacentric curves calculated for actual ships.

Let x represent draughts of water as before, and z the corresponding height of metacentre above centre of buoyancy. The length of ship will not affect the values of z, since it is supposed constant for all draughts, and hence is not introduced. Generally we have

$$z = \frac{y^3}{12\int y dx}$$

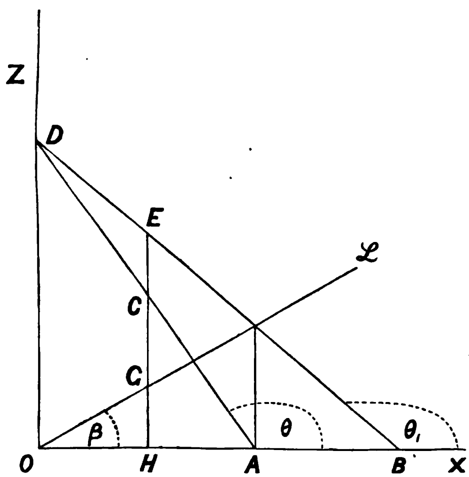
where y is the breadth of section at draught x. Or if $u = \int y dx =$ area of the section up to any draught x — then $\frac{du}{dx} = y$, and

$$z = \frac{\left(\frac{du}{dx}\right)^3}{12u} \text{ or } = \frac{y^3}{12u}$$

In calculating the values of z, one of these forms will be found more convenient to apply than another, according to the form of section. In constructing the metacentric curves, we shall first suppose the draughts x measured along a horizontal axis, and the heights z set up from that line vertically, similar to the method adopted with curves of buoyancy. After this it is necessary to make a peculiar transformation of the curves obtained, in order to conform with the practice adopted in

constructing diagrams similar to Fig. 1. The position of metacentre for any water line as shown by such a diagram is its true position with respect to the keel and water lines, as well as to the corresponding centre of buoyancy. The height of metacentre above the centre of buoyancy added to the height of the latter above a keel line, is the height of metacentre above that line. The algebraic expressions for these heights when added give such heavy equations to deal with, that it is proposed for simplicity to make the following assumptions. The curve of centres of buoyancy is practically straight for some distance above the light draught, as we have already stated. Let it be assumed, then, that the buoyancy curve is a straight line O L passing through the origin of co-ordinates, making a known angle β with the axis x. Any point C on the curve before transformation will be moved vertically up to E by the transformation spoken of—so that G E = H C. After the curve is transformed let it be again referred to the rectangular axes O X, O Z. Then the following relations will exist between the old (x z), and new ($x_{\prime}$ $z_{\prime}$) co-ordinates, viz. :—

FIG. 2.



$$x = x_{\prime} \text{ and } z = z_{\prime} - x_{\prime} \tan\beta$$

Differentiating with respect to x we have

$$\frac{dz}{dx} = \frac{dz_{\prime}}{dx_{\prime}} - \tan\beta$$

or, $\tan\theta = \tan\theta_{\prime} - \tan\beta$

if A D (Fig. 2) be a tangent to a point on the original curve, and B D the tangent to the corresponding point on the transformed curve. The higher differential co-efficients, $\frac{d^2 z}{dx^2}, \frac{d^2 z_{\prime}}{d x_{\prime}^2}$ &c. —whatever be the equations to the original and transformed curves respectively—are identical in the two cases. The degree of the original equation is not altered by this transformation.

Hence the equations to the loci—before and after transformation—are of the same degree and nature.

The height of metacentre above the centre of buoyancy is, as we have already seen, the moment of inertia of the water plane about a fore and aft middle line, divided by the displacement. This is in all cases positive; or, in other words, the metacentre is always above the centre of buoyancy. The keels are of some breadth in all ships, and in the imaginary case of an indefinitely small draught (omitting external keels which produce points of discontinuity in the metacentric curves), the height of metacentre above the centre of buoyancy is infinite—as in the case of an indefinitely thin flat board floating on the water. This shows that for small draughts the height of metacentre is very great, but that it decreases rapidly as the draught of water increases. To counteract this the centre of buoyancy rises as the draught increases. Hence it follows that at a certain draught the metacentric curve and curve of centre of buoyancy would cross, unless a "turning point" existed in the metacentric curve—that is, a point where the latter would be parallel to a horizontal line—and beyond that it ascends again. Such a point does exist for all ships, otherwise the metacentre would be below the centre of buoyancy at some draught—which is impossible. In Fig. 1, it may be observed, the metacentric curve has a turning point at a.

To return to metacentric curves for simple sections. First, let us suppose a rectangular section, as we did in treating of the buoyancy curves. For any draught x measured from the base

$$z = \frac{a^2}{12x},$$

the equation to an equilateral hyperbola, the axes of co-ordinates being asymptotes. The transformed curve will be by substitution

$$z = \frac{a^2}{12x} = z_{,} - x \tan \beta$$

where $\tan \beta = \frac{1}{2}$ (see the first case of the buoyancy curves). Therefore

$$z_{,} = \frac{a^2}{12x} + \frac{x}{2}$$

is the transformed curve referred to the original axes of co-ordi-

nates. By differentiating and supposing $\frac{d z_{,}}{d x} = 0$, we find the "turning point" of this curve is at the draught, $x = \frac{a}{\sqrt{6}}$, that is, when x is a little less than half the breadth of the rectangle. It may be remarked, too, that the transformed curve is a hyperbola (not rectangular) having the vertical axis of co-ordinates and the buoyancy curve for its asymptotes.

Secondly, suppose a triangular section, vertex down—the angle at the vertex being 2α. The metacentric curve, before and after transformation, is a straight line passing through the origin, making an angle with the axis of x, in the latter case, equal to $\tan^{-1}(\frac{2}{3}\sec^2\alpha)$.

If we connect the two previous cases by supposing a triangle beneath a rectangle for a mean section, it is evident we shall have for the locus a straight line through the origin, until the draught reaches the base of the rectangle, and a branch of a hyperbola for all draughts beyond that.

When the transverse section is a circle, the metacentre is at the centre for all draughts. Hence the accurately transformed curve in this example is a horizontal straight line. The equation to the locus of the centre of buoyancy is, however, very complicated, involving transcendental terms.

Let us next consider a rectangular section of breadth a, with a section of any form below the base of the rectangle. Let the area below the base be C, and the draughts x measured from the base line. The locus is a rectangular hyperbola, before transformation. The centre is at the point $\left(-\frac{C}{a},\ 0,\right)$. When transformed, the curve is still a hyperbola having the same centre as before, with the "turning point" at a draught which is little less than half the breadth of the rectangle.

Now suppose a section with "tumble home" straight lines for sides, each side making an angle α with the vertical, and let the breadth of the base be a. The metacentric curve before transformation will have for its equation

$$z = \frac{(a - 2x\tan\alpha)^3}{12(a - x\tan\alpha)x}$$

This is of the third degree, and hence will be so after it is transformed. The maximum value of z is infinity, where the

draught is zero, and its least value is zero, when the draught reaches the vertex of the triangle formed by producing the sides of the section to meet. The transformed curve will always be *convex* to the axis of x, and the "turning point" exists where the draught equals the height of the triangle.

Suppose the section of the last case to be placed on top of a section of any form, measuring draughts from same line as before. The equation to the metacentric curve is the same in degree and form as for the previous case; but the additional area of section introduces the first power of the variable z which does not appear in that case.

If the sides of the section "flare out" and make an angle a ($> 90°$) with the vertical, we get the same equation as in the previous cases, only $\tan a$ is now negative. Two infinite values can be obtained for z in this case—viz., when the draught is zero, and when it is infinite. The curve is always *convex* to the horizontal axis. The remarks which were made upon the addition of an area of any form below this section apply also to this case.

To sum up, the curve of buoyancy for a ship of ordinary form is *concave* to a horizontal line at the keel, and is straight, practically, between the light and load lines, making angles varying between 28° and 30° with the horizontal. The metacentric curve is always convex to the horizontal line through the keel, and the "turning point" is found to exist between $\frac{3}{5}$ and $\frac{2}{5}$ the breadth of the mean section at the light draught. For all draughts beyond the "turning point" the metacentre increases in height above the centre of buoyancy, as the draught increases.

REMARKS ON ROLLING IN A SEAWAY.

ONE of the most interesting papers in the Report of the Committee on Designs for Ships of War recently presented to Parliament is that by Professor Rankine, entitled "Remarks on the Stability of Mastless Ships of Low Freeboard as affected by the Waves." All the conclusions of the Committee in connection with this subject are based upon the results obtained by Professor Rankine, and endorsed by the Scientific Sub-Committee, so that a few remarks respecting the method of investigation will not be without value. In order to facilitate reference, a reprint of Professor Rankine's paper is appended.

The formula upon which the calculations are based was obtained by Mr. Froude, and is as follows:—

$$\frac{-\Theta}{\theta - \Theta} = 1 - \frac{T^2}{t^2}$$

in which

Θ = steepest slope of the wave.
θ = the maximum angle of the ship's roll relatively to the horizon.
T = wave period.
t = natural period of the ship.

This equation is derived from the following assumptions:—

1. That the waves are all equal and of a uniform period.
2. That the waves are all of a definite trochoidal form.
3. That the reaction of the water pressure on the ship is always perpendicular to the surface of the wave at the part occupied by the ship.
4. That the time of oscillation of the ship, in smooth water, is the same for all angles.

None of these assumptions can be regarded as accurately true, and one or two of them are plainly very rough approximations to the truth. For this reason I have always regarded Mr. Froude's formula as exhibiting the general aspects only of

the rolling of ships in waves, and not as affording any trustworthy means of calculating the extent of the roll in any practical case.

The assumption that the time of oscillation of the ship is the same for all angles is alone sufficient to make it necessary to regard this formula with considerable reserve, when it is applied, as in the case under notice, to calculate the rolling of actual ships; because their times of oscillation are far from being the same for all angles, a fact upon which considerable stress is laid in the Report of the Committee.

Professor Rankine's investigation, therefore, applies Mr. Froude's formula to a case of which the conditions differ greatly from the assumptions upon which the formula rests. Apart from this fundamental objection, it appears that in conducting the investigation several additional assumptions have been made which must be regarded with distrust. For example, it is assumed that the wave observed by Scoresby in a passage across the Atlantic is a fair representative of the most dangerous waves to which ships will be exposed; but this is by no means certain. Again, it is assumed that the metacentric period for ships will vary with the amplitude of the oscillations, in the same manner as in a common pendulum, the total range in the stability of the ship being compared with an amplitude of 180 degrees in the pendulum. No mention is, however, made of the similar variation that may take place in the time of the waves, although such variation would seriously affect the investigation. Moreover, in a new design, the position of the centre of gravity and the length of the radius of gyration can only be estimated, and consequently the approximation to the metacentric period may be liable to considerable error, the effect of which is important. As an example of this, it may be stated that if the period for the *Devastation* had been taken as 11 seconds instead of 14 seconds in the application of Professor Rankine's method, the maximum roll of the ship would have been found 5 degrees greater than that given in the Report. In view of these assumptions, and the errors possibly arising therefrom, the results of the Committee's investigation cannot be regarded as thoroughly trustworthy. These results are practically summed up in the Report by the statement that 39 degrees is a sufficient range of stability for large sea-going iron-clads to make them

Fig 1

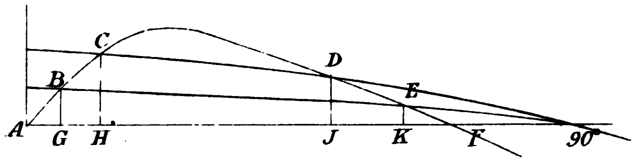


Fig 2

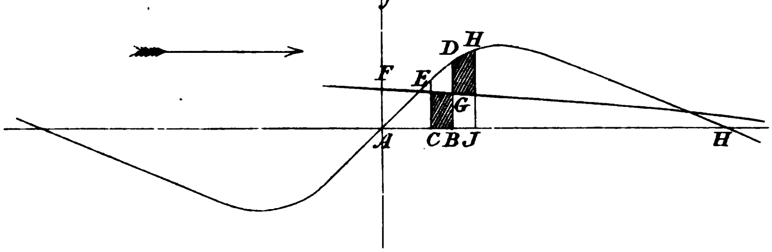


Fig 3

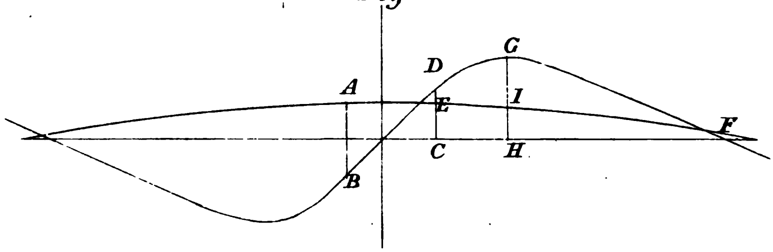
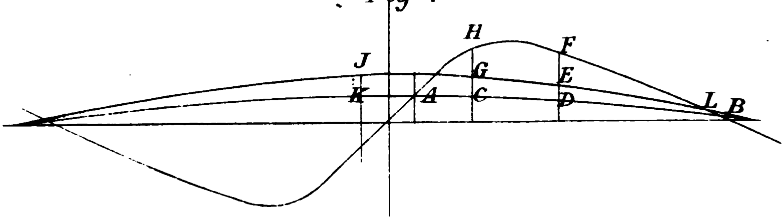


Fig 4



safe when rolling among waves, supposing them to be without sail.

When we pass from the case of a mastless ship to that of a sailing ship rolling among waves, a still more difficult problem is encountered.

One method of investigation that has been suggested may be briefly described as follows :—Assuming that a definite angle has been determined for the vessel when rolling without sail among waves, it is proposed to divide the curve of stability into two parts, one being assigned to resist the action of waves, and the other to provide for the effect of the wind on the sails. Supposing Fig. 1 to represent the curve of stability by the line A B C D E F, and C D to be a "wind-curve," assumed to vary as the square of the cosine of the inclination, the curve C D is so placed on the curve of stability as to cover a range equal to that which would be considered sufficient if the vessel had no sail. The part thus cut off from the top of the curve of stability is considered to provide a margin against the rolling produced by the heave of the sea; A C is devoted to the wind, and half of it, A B, is taken as the greatest steady heel under sail consistent with safety.

It appears to me that the details of this method rest upon no valid foundation. First of all, one finds a definite angle selected as the necessary range of stability for the ship, considered without sail; and this has been shown to be a question yet remaining without satisfactory solution. But even accepting this angle as fixed, the mode in which the combined effect of wind and waves is estimated is open to important objections.

Referring to Fig. 1, and remembering that the interval between the curve of stability and the wind-curve C D is devoted to resisting rolling produced by the waves alone, it will be seen that the front part of the curve from A to C is left to resist the action of the wind on the sails. Hence if, in all cases, the wind came on very gradually, the ship might be safely sailed with a permanent heel represented by A H. But as the wind may come on suddenly, as a gust, A C is divided into two equal parts at B, and A G is taken as the greatest steady heel for safe sailing. If the ship were upright, and at rest, when a wind suddenly acted upon her (the pressure of which would be sufficient to hold her steadily inclined at G), and if it were to continue

constant after its sudden application, it would incline the ship as far as H. The supposition is that she would then be safe, because the roll caused by the heave of the sea has already been assumed to be amply provided against by the part of the curve of stability between C and D.

On consideration it will be evident that in thus dividing the curve, a greater range is actually devoted to providing against the heave of the sea than is intended. To absorb the effect of a gust, the front part of the curve from A to H is made double what is required for the steady heel under sail; but by placing the curve C D as described, it is tacitly assumed that the double power of the wind must be provided for at the other end of the curve also, and for this no reason appears. If B E is the wind-curve belonging to the greatest safe steady heel, then the curve from C to E will be the portion of the curve of stability really devoted to rolling in waves with the intensity represented by the wind-curve B E. If this wind were blowing steadily there would be the portion B E of the curve of stability to provide against rolling in waves. And if A C is sufficient to provide for the gust, then, as is said above, C E, not C D, is available to resist rolling in waves.

This objection is, it will be observed, made upon the assumption that the principle of thus subdividing the curve of stability is admitted; but it does not appear that any justification can be found for such division, and this of course is a radical objection to the whole method. The two actions, of the sea and the wind, must generally go on together, and extend over the same portions of the curve of stability, so that it appears improper to devote one portion to the gusts of wind and another to the heave of the sea.

It would, I think, be more nearly consistent with the conditions of a ship under sail and rolling in waves to suppose her to be rolling in the worst waves she is likely to meet and to suppose her sails to be struck by a squall at that part of her roll at which the gust would be most dangerous.

For instance, suppose Fig. 2 to show a curve of stability of a ship, which may be assumed to be rolling to leeward under the influence of the waves alone, and with such an oscillation that the roll would end at B D. When she arrives at E a gust may be supposed to strike her, which is represented by the wind-

curve F G K, and so the ship is made to roll beyond the position B D to another position, J H, such that the area G H is equal to the area C G. It is evident that the greater the area C G the greater will be the additional angle of roll due to the action of the wind. It is also evident that the area of C G is greater the earlier in the roll to leeward when the wind begins to act. Hence the worst point of the roll at which the wind can begin to act is when the ship has reached the limit of the roll to windward.

This case is represented in Fig. 3. A B is the extreme windward position of the ship when rolling, which roll would, without any wind, end at C D to leeward. But at A B the wind begins to blow with an intensity represented by the wind-curve A F, and the roll is thus increased, ending at G H instead of C D. The position of G H is fixed by the condition that the area D E I G shall equal the area A C, and the ship would be safe so long as the area D E F G was greater than the area A C.

Another imaginable case is that where a ship is rolling among waves with a steady pressure of wind, the power of which becomes suddenly doubled at the worst part of the roll. This case is represented in Fig. 4, where K B is the wind-curve for the steady pressure, J K and H C are the extremes of the roll before the power of the wind is increased, and J G E is the wind-curve for the suddenly increased intensity which is assumed to take place when the ship is in the position J K. The gust will cause the roll to be lengthened, say, to the position D F, the area H G E F being equal to the area J K C G; and in this case the ship will be safe so long as the area H G L F is greater than the area J K C G.

This mode of regarding the subject is by no means free from objection, but I consider it preferable to that previously described, and as more nearly representing the kind of action that must go on when a ship under sail is rolling in the trough of the sea.

One objection to both methods appears on the surface; viz.—that while the curve of stability has reference to the inclination of the ship to the wave-surface, the wind-curve has relation to the inclination of the ship to the horizon. In the foregoing case, therefore, the effect of the wind has probably been reckoned

greater than it should be, since it has been taken in proportion to the change of inclination to the surface of the wave, instead of in proportion to the change of inclination to the horizon.

At present I do not see a way to overcome these objections and difficulties, nor should I regard either method of investigation as affording trustworthy means of calculating the precise amount of stability which would be required for new designs. The only safe guide in this matter is, in my opinion, found in experience with successful ships, and in designing new vessels it appears desirable to provide that amount and range of stability which have been proved sufficient in ships that have been thoroughly tried.

J. C.

REMARKS ON THE STABILITY OF MASTLESS SHIPS OF LOW FREEBOARD, AS AFFECTED BY THE WAVES.

Submitted to the Scientific Sub-Committee by Professor Rankine.

1. The danger of excessive heeling or of overturning, in a ship subjected to the action of the waves alone, becomes greatest when she lies in the trough of the sea amongst waves whose periodic time from crest to crest is equal to the natural periodic time of a double roll of the ship; for then there is a tendency, through the coincidence of the successive impulses given by the waves, with the successive rolls of the ship, to increase indefinitely the angle of roll. (See Froude, Trans. I. N. A., 1862; also Rankine, ditto, 1864.)

2. This danger obviously occurs to the full extent in those ships only whose rolling is isochronous, large and small rolls being performed in equal periods.

3. But low-freeboard ships are very far from being isochronous in their natural rolling. In them the periodic time of rolling is least for indefinitely small angles of roll (being equal to that of a simple pendulum whose length is a third proportional to the metacentric height and the radius of gyration. This pendulum may be called the *metacentric pendulum*, and its period the *metacentric period*). As the angle of roll increases, the periodic time increases. (Its rate of increase may be deduced from the curve of stability, by means of a method described by Moseley, "Mechanics of Engineering and Architecture.") When that angle approaches the angle of vanishing stability, the periodic time of rolling increases indefinitely.

4. Hence it follows that when such a ship has a rolling motion impressed on her, even by waves whose periodic time is exactly equal to her own period for a certain angle of roll, the coincidence of period continues only so long as the angle of the roll is not sensibly increased. The increase of that angle gradually destroys that coincidence, and moderates or removes the danger arising from it.

5. It is well known that a similar increase of periodic time with amplitude of oscillation occurs in a simple pendulum. The angle of vanishing stability

in this case is 180°, when the pendulum points vertically upwards. It has been shown by mathematicians that the law connecting the period with the amplitude is expressed by means of an elliptic function (see "Legendre, Traité des Fonctions Elliptiques," chap. viii.) The following are examples of the results:—

Angles of swing—	Very small	30°	60°	90°	120°	150°	180°
Ratios of period to that of small oscillations—	1	1·017	1·073	1·183	1·373	1·762	infinite.

6. When the curve of stability of a ship approximates to a curve of sines, the law of her natural rolling is approximately the same with that of a simple pendulum, equal in length to the metacentric simple pendulum, and swinging through angles greater than the angles of roll of the ship in the same proportion in which 180° is greater than her angle of vanishing stability. For example, let the angle of vanishing stability be 42°, then for the following angles of roll—

Very small	7°	14°	21°	28°	35°	42°

the ratios of the periodic time to the metacentric period will be as follows:—

1	1·017	1·073	1·183	1·373	1·762	infinite.

7. It has been shown, in the previous researches already referred to, that during the unresisted rolling of ships amongst a series of large waves, the extent of roll of the ship *relatively to the wave-surface*, is to the steepest slope of the wave-surface nearly as—

$$t^2 : T^2 - t^2 ;$$

in which t denotes the natural period of the ship, and T that of the waves. In symbols, let Θ be the steepest slope of the waves, and θ the angle of roll of the ship *relatively to the horizon*, then

$$\frac{-\Theta}{\theta - \Theta} = 1 - \frac{T^2}{t^2} \quad \cdot\cdot \quad \cdot\cdot \quad \text{(A)}.$$

According to the same principles, the extent of roll *relatively to the horizon* is to the extent of roll *relatively to the wave-surface*, as the square of the period of the waves is to the square of the natural period of the ship; that is to say:

$$\frac{\theta}{\theta - \Theta} = \frac{T^2}{t^2} \quad \cdot\cdot \quad \cdot\cdot \quad \text{(B.)}$$

8. In combining this principle with that previously stated, it is obvious that the value of the natural period of the ship will depend on the angle of roll *relatively to the wave-surface*. Suppose, then, that we assume a given angle of roll relatively to the wave-surface, $\theta - \Theta$, and determine the corresponding natural period of the ship; equation A will enable us to determine, to a rough approximation, the angle of wave-slope which will produce that angle of roll, relatively to the wave-surface; and equation B will show the corresponding angle of roll relatively to the horizon. The negative sign of Θ in equation A shows that when t is greater than T (as it ought always to be in vessels designed for steadiness) the slope of the wave is contrary in direction to the roll of the ship.

9. To exemplify these principles by calculation, we will assume that the metacentric period is *equal* to that of the waves; being the *least* value con-

sistent with steadiness. We will also take for the angle of vanishing stability, as before, 42°. Then we have the following results :—

Angles of roll relatively to the wave surface—

0°	7°	14°	21°	28°	35°

Angles of slope of wave-surface (negative)—

0°	0·23°	1·83°	6·0°	13·2°	22·7°

Angles of roll relatively to horizon—

0°	6·77°	12·17°	15·0°	14·8°	11·3°

10. It appears to have been well ascertained that no wave whose period approaches to the metacentric period of a large iron-clad ship (say from 10 to 15 seconds) has a slope nearly so steep as 13°. Hence, according to the preceding calculations, we may conclude, that a ship whose angle of vanishing stability is 42° would roll, amongst such waves, to an angle not exceeding 15° relatively to the horizon, or 28° relatively to the wave-surface, and would still be more than 14° from her position of vanishing stability; and this calculation is made without considering the fact, that the *effective* wave-surface, on which the motions impressed on the ship depend, passes nearly through her centre of buoyancy, and is less steep than the upper surface of the waves.

11. It is not to be expected that the results of such theoretical calculations as these will be exactly verified in practice; but the errors are on the safe side, for they consist mainly in neglecting such circumstances as the steadying effect of bilge keels, and of the friction of the water, and the want of isochronism in the waves.

12. Results of calculations for vanishing stability at 39°:

Angles of roll relatively to wave surface—

0°	6½°	13°	19½°	26°	32½°

Angles of slope of wave-surface (negative)—

0°	0·21°	1·7°	4·4°	12·3°	22°

Angles of roll relatively to horizon—

0°	6·29°	11·3°	13·9°	13·7°	10½°

13. The angle of roll relatively to the horizon has a maximum when the angle of roll relatively to the wave-surface is about ·567 of the angle of vanishing stability. The value of that maximum is about ·366 of the angle of vanishing stability.

14. The following appear to be the practical conclusions to be drawn from the preceding principles :—

First—A mastless ship of low freeboard ought to have her metacentric period *not less* than that of the longest waves which she may have to encounter, otherwise she will be liable to unsteadiness.

Secondly—She will have a margin of stability amongst waves of a period not greater than her own metacentric period, when the steepest slope of the waves is as much as three-tenths of her angle of vanishing stability.

[Revised in consultation with Sir William Thomson, 21st February, 1871.]

(Signed) W. J. MACQUORN RANKINE.

ROYAL SCHOOL OF NAVAL ARCHITECTURE AND MARINE ENGINEERING,

SOUTH KENSINGTON, W.

OFFICERS OF THE SCHOOL.

Inspector-General	REV. JOSEPH WOOLLEY, LL.D., F.R.A.S.
Principal	CHARLES W. MERRIFIELD, F.R.S.
Vice-Principal	JAMES H. COTTERILL, M.A.
Instructor in Marine Engineering	W. CAWTHORNE UNWIN, B.SC.
Instructor in Shipbuilding .	WILLIAM B. BASKCOMB, M.I.N.A.
Instructor in Naval Design .	WILLIAM H. WHITE, F.R.S.N.A., M.I.N.A.
Instructor in Marine Engine Drawing	JOHN MAXTON.
Instructor in Practical Chemistry	JOHN DAVIDSON.
Instructor in French . . .	JULES PENON.

The Lords of the Committee of Council on Education, after communication with the Admiralty and the Institution of Naval Architects, opened at the South Kensington Museum, in the year 1864, a School of Naval Architecture and Marine Engineering.

This School is for the instruction not only of Admiralty pupils from the Royal Dockyards, and Officers of the Royal Navy, but also of Naval Architects and Ship Builders, Marine Engineers, Foremen of Works, Shipwrights, and other persons desirous of studying Naval Architecture and Marine Engineering. The course of instruction is calculated to last for four sessions, on the supposition that the student enters the School with a fair knowledge of Drawing and Practical Geometry, and an elementary knowledge of Mathematics and Physics. The instruction embraces the subjects specified for the final examinations. While there is room, students may be admitted to the Special Classes on Professional Subjects, without attending the general course.

The Session of the School commences on the 1st of October, and lasts till the 30th of the following April. The students are expected to pass the summer five months in practical work, either in a Dockyard or in a Marine Engine Factory, public or private.

ADMISSION.

The fee (payable in advance) for the full course of instruction is £25 for each session of seven months, or £80 for the course of four sessions.

Students who have already paid one fee of £25 are allowed to compound for the next three sessions by a payment of £60 at the commencement of the second session. Students who have already paid the fees for two sessions are allowed to compound for the two remaining sessions by a payment of £42 at

the commencement of the third session. Students allowed to join the School after Christmas are charged £5 for each remaining month of that session unless they prefer to compound.

Proportionate fees are charged to students attending Special Classes only. Officers in Her Majesty's Service are admitted to the full course on payment of £10 per session.

Persons desiring admission must apply by letter to the "Secretary, Science and Art Department, South Kensington, London, W."

Lectures.

Courses of Practical and Experimental Lectures (see Lecture List appended, p. 144), which may be attended separately, are given on such of the subjects of instruction as admit of, or require, illustration by this means.

The public is admitted to these Lectures on payment of a fee of £1 1s. for the full course; or to each separate Lecture on payment of 1s. Officers in Her Majesty's Service, not attending the School, are admitted at reduced fees on application by letter addressed to the Secretary.

. . . . .

School Scholarships and Free Studentships.

Four Free Studentships, to two of which are attached Scholarships of £50 per annum, tenable for four sessions, are given in competition at the commencement of each session if qualified candidates present themselves. They are only open to students on entering; but if not all filled up in any one year, students who have studied for one or two sessions at the School can compete for as many as be vacant, should the examination passed by them at the end of the previous session have been very satisfactory. No person is permitted to compete who has not already been admitted as a student, and paid the fee, which will be returned to him in the event of success.

The subjects of the Competitive Examination, with the number of marks assigned to each, are as follows :—

1. Pure Mathematics, including Arithmetic, Plane and Descriptive Geometry, Plane Trigonometry, and the Elements of the Differential and Integral Calculus ...	2,500
2. Theoretical and Practical Mechanics, or Applied Mathematics	1,500
3. Practical Shipbuilding	2,000
4. Marine Engine and Engineering	2,000
5. Physics	500
6. Chemistry	500
7. Mechanical and Professional Drawing	500

This examination is not open to Admiralty students, nor to any but British subjects.

Admiralty Scholarships.

The Lords Commissioners of the Admiralty have made the following arrangements for a Competitive Examination for the admission of persons not already in the Government Service to the School as Admiralty students :—

Candidates are examined either as Naval Architects or as Marine Engineers; they must not be less than 18 or more than 21 years of age, and must have served at least two years in a dockyard or in an Engineering Establishment, or must give satisfactory proof of having in some way been so connected with Shipbuilding or Engineering operations as to have become well grounded in the elementary principles and practice thereof.

Those candidates who may be selected will be treated while attached to the School in all respects as the Admiralty students, and will receive wages, commencing at 1s. 6d. per day, for six days per week for first year, increasing yearly 3d. per day till they reach 2s. per day; and, in addition, a subsistence

allowance of 3s. per day, for seven days per week, while they are away from their homes, either at the School or in the Royal Dockyards.

It is to be understood that the Admiralty makes no engagement to employ these students after the completion of their course of study; they must rely on their own worth as educated Naval Architects or Marine Engineers for obtaining employment in their subsequent career.

The subjects of the Competitive Examination, with the number of marks assigned to each, are as follows:—

1. Pure Mathematics, including Arithmetic, Mensuration, Plane and Descriptive Geometry, Plane Trigonometry, and the Elements of the Differential and Integral Calculus ...	2,500
2. Applied Mathematics, including Mechanics and Hydrostatics ...	1,000
3. Practical Shipbuilding, including Laying Off (for Naval Architect Candidates only) ...	2,500
4. Practical Marine Engineering (for Marine Engineer Candidates only)...	2,500
5. French ...	500
6. Elements of Physics and Chemistry ...	750
7. English Grammar and Composition ...	750
8. Geography and History ...	750

No Candidate will be admitted to the School who does not obtain at least two-thirds of the full number of marks in the first and second subjects, and three-fifths of the full number either for Practical Shipbuilding or Marine Engineering. The last four subjects, although counting in the competition, will not be considered obligatory.

This examination is only open to British subjects.

The time and place of examination, the number of students to be selected, and full particulars, are advertised in the *Times* in June every year.

Collateral Advantages.

Permission to devote the five summer months to actual work and the acquirement of practical knowledge in the Royal Dockyards is granted by the Admiralty to all Private Students of the School being British subjects. Arrangements are occasionally made for the students to visit Public and Private Works, by the courtesy of the owners and authorities of the establishments.

Hours of Study.

The usual hours of study are from 9 to 12 and from 2 to 5 on Mondays, Tuesdays, Thursdays, and Fridays, and from 9 to 12 only on Wednesdays and Saturdays. The Public Lectures take place from 5 to 6 p.m. on two or three evenings weekly.

Inspection.

All the students are examined at the end of each session: at the end of his fourth session each student is examined for the Diploma of Associate or Fellow of the School.

Examination for Diplomas.*

Diplomas are granted to all persons, whether they have received their instruction at the School or not, who pass the final examinations, provided they give satisfactory evidence of having gone through the course of practical work recommended by the Council of the Institution of Naval Architects. These Diplomas are of two grades according to the success of the candidate in the examination, the title of the higher grade being Fellow, and of the lower

* The next examination will take place in April, 1872. Candidates desirous of being examined then should apply without delay to the Secretary of the Science and Art Department for detailed information.

Associate of the Royal School of Naval Architecture and Marine Engineering. This examination is held annually towards the end of April.

In case of failure at the Examination the student may either remain at the School for another session at a fee of £25, or he may present himself at any future examination whenever he considers himself qualified.

Candidates who have not been students of the School are required to produce certificates that they have been engaged for at least three years in—

1. Practical wood or iron shipbuilding in a Dockyard; or,
2. Practical engine and boiler building in a Dockyard, or in a Marine Engine Factory; or,
3. Practical work as a Draughtsman in a Dockyard or in a Marine Engine Factory, during which the candidate himself must have gone through the complete formation of the design of a ship, or of a marine engine, with the whole of the designs included in it.

Such candidates are also required to give references as to character and good conduct before being admitted to the examination.

All such candidates must apply to the "Secretary, Science and Art Department, South Kensington, W.," not later than the 15th March in each year.

Candidates are examined either as Naval Architects or as Marine Engineers.

SUBJECTS AND MARKS FOR THE DIPLOMA OF ASSOCIATE.

GROUP A.

Naval Architects.	No.	*Marine Engineers.*	No.
Practical shipbuilding	1,000	Practical Engineering	1,500
Laying off	1,000	Proportions and arrangement of marine engines, boilers, and propellers	1,500
Usual calculations of a ship	1,000	*Elementary physics	1,000
*Elementary physics	1,000	Strength of materials	500
Strength of materials	500	Heat and steam	500
Heat and steam	500		
	5,000		5,000

GROUP B.

Naval Architects and Marine Engineers.	No.
Arithmetic and mensuration	1,000
Algebra, including quadratic equations; and Euclid, first six books and 22 propositions of Book XI., with deductions	1,000
†Plane trigonometry and logarithmic calculation	1,000
§Elementary mechanics and hydrostatics	1,000
	4,000

GROUP C.

Naval Architects.	No.	*Marine Engineers.*	No.
‖Ship Drawing	1,000	‖Engine Drawing	1,000
Total marks possible	10,000	Total marks possible	10,000

Note.—Half the possible marks to be obtained in each of the three groups as a condition of the ASSOCIATE's diploma. The schedule will be revised from time to time as occasion may require.

* An elementary knowledge of chemistry, electricity, and magnetism, with especial reference to the errors of compasses of ships, both of wood and iron.

† Plane trigonometry, as usually read, exclusive of trigonometrical analysis.

§ Including (*inter alia*) the description and explanation of the principal mechanical and hydrostatical instruments and machines, specific gravity, and the flotation of bodies.

‖ The ship and engine drawing will be done by the candidate at home "on honour." Instructions will be sent to any candidate applying in proper time.

SUBJECTS AND MARKS FOR THE DIPLOMA OF FELLOW.

GROUP A.

Naval Architects.	No.
Design of a ship	500
Principles of design of a ship	500
Practical shipbuilding and laying off	1,000
†The steam-engine	500
Heat and steam	500
Strength of materials and structures	750
§Physics	500
‖Chemistry and properties of metals	750
	5,000

Marine Engineers.	No.
Design of a pair of marine engines with boilers and propeller	500
*Principles of design of marine engines, boilers, and propellers	750
†Practical engineering	750
Practical shipbuilding	500
Heat and steam	500
Strength of materials and structures	750
§Physics	500
‖Chemistry and properties of metals	750
	5,000

GROUP B.

Naval Architects.	No.
¶Pure mathematics	1,500
**Applied mathematics	2,000
Propulsion and resistance of ships and theory of waves	750
Stability and oscillations of ships	750
	5,000
Total marks possible	10,000

Marine Engineers.	No.
¶Pure mathematics	1,500
**Applied mathematics	2,000
Propulsion and resistance of ships and theory of waves	750
††Mechanical theory of heat	750
	5,000
	10,000

Note.—At least 2,500 marks must be obtained in each of the two groups A and B as a condition of the FELLOW'S diploma. In case of failure, the examiner will judge whether the knowledge shown by the candidate is sufficient to admit of his being received as an *Associate*.

* Including a knowledge of the arrangement and proportions of simple and compound marine engines and their appendages; of the mode of representing slide valve motions, and of the use of the indicator; and of the rules for calculating the power of engines and performance of vessels, and the efficiency, evaporation, consumption of fuel, and strength of boilers.

† Including a knowledge of the processes of an engineering factory, of the construction and mode of operation of engines and machinery generally, and of the working of engines on ship-board.

§ Including the elements of pneumatics, electricity, and magnetism, with its application to ships, both of wood and iron.

‖ A fair knowledge of inorganic chemistry and qualitative analysis.

¶ The pure mathematics will involve a fair knowledge of the calculus, including (*inter alia*) the elementary parts of calculus of finite differences, and of the calculus of variations, and of differential equations, of analytical geometry of three dimensions, and of descriptive geometry, a thorough acquaintance with the principles of the mensuration of shipbuilding [or marine engineering].

** The applied mathematics will include such subjects as are chiefly useful to naval architects and marine engineers, such as statics, dynamics, hydrostatics, hydrodynamics, theory of internal stress and of elasticity, with the applications of these subjects to the strength of materials and structures, and to machinery.

†† In its application to the theory of the steam-engine.

BOOKS.

The following is a list of the books at present used in the School:—

	Publishers.
Aldis's Solid Geometry	Deighton, Bell, & Co.
Besant's Elementary Hydrostatics	„
„ Hydrostatics and Hydrodynamics	„
Boole's Differential Equations	Macmillan.
„ Finite Differences	„
Cotterill—Notes on the Theory of Heat	Spon.
Drew's Geometrical Conic Sections	Macmillan.
Evans' Elementary Manual for the Deviations of the Compass in Iron Ships	J. D. Potter.
Golding Bird and Brook's Natural Philosophy	Churchill.
Goodeve's Elements of Mechanism	Longman.
Logarithms of Useful Knowledge Society	Walton & Maberly.
Main and Brown's Steam Engine	Longman.
„ Indicator and Dynamometer	„
Parkinson's Elementary Mechanics	Macmillan.
Rankine's Applied Mechanics	Charles Griffin.
„ Steam Engine	„
Reed's Shipbuilding in Iron and Steel	Murray.
Roscoe's Chemistry	Macmillan.
Routh's Rigid Dynamics	Macmillan.
Shipbuilding, Theoretical and Practical, by Watts, Rankine, and others	Mackenzie.
Tait and Steele's Dynamics of a Particle	Macmillan.
Todhunter's Algebra	„
Todhunter's Analytical Statics	„
„ Conic Sections	„
„ Differential Calculus	„
„ Euclid	„
„ Integral Calculus	„
„ Plane Trigonometry	„
„ Spherical Trigonometry	„
„ Theory of Equations	„
Twisden's Practical Mechanics	Longman.
Woolley's Descriptive Geometry	„

LECTURES.

Courses of Public Lectures given in connection with the School from 5 to 6 o'clock in the evening on the days stated below. (Session of 1871-2.):—

Subjects.	Lecturer.	Dates.
On Magnetism.	W. H. Barrett, Esq.	6th, 13th, 20th, and 27th Oct., and 3rd and 10th Nov.
On Metallurgy,	John Percy, Esq., M.D., F.R.S.	14th, 21st, and 28th Nov., and 5th, 12th, 19th Dec., 1871.
On the principal elements of offensive and defensive power in ships of war.	N. Barnaby, Esq., President of the Council of Construction of the Royal Navy.	24th Nov., 1st, 8th, 15th, and 22nd Dec., 1871.
On Marine Engineering.	E. R. Allfrey, Esq. ...	5th, 12th, 19th, and 26th Jan., 2nd, 9th, 16th, and 23rd Feb., 1st and 8th March, 1872.
On the Elements of Heat.	Dr. Guthrie	2nd, 9th, 16th, 23rd, and 30th Jan., 1872.
On the fitting of Naval Ordnance.	Capt. Scott, R.N. ...	6th, 13th, and 20th Feb., 1872.
Theoretical Explanation of the Manœuvres of a Ship under Sail.	Capt. Sir L. Heath, K.C.B.	27th Feb., 5th and 12th March, 1872.

LIST OF PRESENT STUDENTS OF THE SCHOOL.

NAVAL ARCHITECTS.			MARINE ENGINEERS.		
Name.	A, Admiralty Student. P, Private Student.	Where from.	Name.	A, Admiralty Student. P, Private Student.	Where from.
		Entered in 1868.			
BAILEY, Charles Pink	A	H.M.D. Portsmouth.	[2] ANIS, Mohammed	P	Cairo.
BLACK, John...	A	H.M.D. Devonport.	[2] ARIF, Mahommed	P	Cairo.
PHILLIPS, Thomas	A	H.M.D. Pembroke.	BUTLER, Richard Jago	A	H.M.S.F. Keyham.
STANLAKE, John	A	H.M.D. Devonport.	CHILCOTT, William Winsland ...	A	H.M.S.F. Woolwich.
TURPIN, William Woodley	A	H.M.D. Portsmouth.	CORNER, John Thomas	A	H.M.S.F. Sheerness.
			[2] NAGY, Husseyn	P	Cairo.
			SEATON, Albert Edward	A	H.M.S.F. Keyham.
		Entered in 1869.			
DAVIES, Lewis George	A	H.M.D. Sheerness.	MAYSTON, Robert	A	H.M.S.F. Portsmouth.
JAMES, William	A	H.M.D. Pembroke.	WAGHORN, John Waghorn Webb ...	A	H.M.S.F. Keyham.
SMITH, Alfred Weymouth	A	H.M.D. Portsmouth.	*WATTS, Luther	P	Portsmouth.
SMITH, William Edward	A	H.M.D. Portsmouth.			
		Entered in 1870.			
ALLINGTON, James	A	H.M.D. Devonport.	BAKER, George Henry	A	H.M.S.F. Keyham.
[1] ARTSAYOOLOFF, Constantine ..	P	St. Petersburg.	McADAM, John Alfred	P	Hereford.
CHAMPNESS, Henry Robert... ...	A	H.M.D. Chatham	MILTON, James Tayler	A	H.M.S.F. Portsmouth.
[1] GOULAEFF, Ernest	P	St. Petersburg.	ROBINS, Samuel John...	A	H.M.S.F. Keyham.
McDONALD, John Norman... ...	A	H.M.D. Sheerness	RUDD, Charles...	A	H.M.S.F. Portsmouth.
			WALKE, Andrew James	A	H.M.S.F. Keyham.
		Entered in 1871.			
GOULD, Alfred Hugh	A	H.M.D. Portsmouth.	LINNINGTON, Edward Albert... ...	A	H.M.S.F. Portsmouth.
MARSHALL, James Brown	A	H.M.D. Portsmouth.	PELLOW, Charles Henry	A	H.M.S.F. Keyham.
YATES, James Alfred...	A	H.M.D. Portsmouth.	PITT, Cornelius	A	H.M.S.F. Sheerness.
			RULE, Thomas	A	H.M.S.F. Sheerness.
			SHAPCOTT, Richard Arthur	A	H.M.S.F. Keyham.
			SOPER, Thomas	A	H.M.S.F. Keyham.

* Holds the School Scholarship of £50 per annum.

1 Sent by the Russian Government. 2 Sent by the Egyptian Government.

LIST OF FORMER STUDENTS OF THE SCHOOL.

NAVAL ARCHITECTS.

Name.	A—Admiralty Student. P—Private Student.	Date of Entry.	Date of Departure.	Diploma. A—Associate. F—Fellow.*	Where from.	Present Employment.	Position held.
a Blom, H. A....	P	1866	1867	—	Christiania	Norwegian Royal Navy	Lieutenant.
Bone, William James	A	1864	1867	F_2	H.M.D., Dvnpt.	Cole Bros., Willington Quay	Manager.
Brown, Alexander McDonald	P	1865	1868	—	Rotterdam	H.M. Dockyard, Chatham	
Cearns, John Frederick ...	P	1867	1871	A	H.M.D., Chatham	Earle's Shipbdg. & Engineering Co. (Limited), Hull	Draughtsman.
Cotsell, James	A	1867	1871	F_3	H.M.D. Ptsmth.	H.M. Dockyard, Portsmouth	Draughtsman.
Deadman, Henry Edward ..	A	1864	1867	F_2	H.M.D., Chtham.	H.M. Dockyard, Devonport	Foreman of the Dockyard.
Edwards, Thomas	A	1867	1871	F_2	H.M.D., Pembroke	The Admiralty, Whitehall, S.W. (temporarily.)	Draughtsman.
Elgar, Francis	A	1864	1867	F_1	H.M.D., Ptsmth.	Earle's Shipbdg. & Engineering Co. (Limited), London	Designer.
Ewens, Paul...	P	1864	1865	—	London	Laird Bros., Birkenhead	Draughtsman.
b Fareed, Hassan	P	Dec. 1868	1869	—	Alexandria		
Fitze, William James ...	A	1864	1867	—	H.M.D., Dvnpt.	J. and W. Dudgeon, Cubitt Town, E.	Assistant Overseer for Admiralty.
Gandy, Charles	P	Dec. 1865	1868	—	London		*Left the profession.*
Gowings, William	A	1864	1867	F_2	H.M.D., Dvnpt.	The Admiralty, Whitehall, S.W. (temporarily.)	Draughtsman.
Grierson, Frank Willisford	P	1868	1871	—	London.		*Left the profession.*
Hansen, George Edward ...	P	1867	1868	—	Cowes, I. of W.	C. Hansen, shipbuilder, Cowes	
b Hishmat, Mohammed ...	P	Dec. 1868	1869	—	Alexandria		
John, William	A	1864	1867	F_1	H.M.D., Pmbrk.	The Admiralty, Whitehall, S.W.	Draughtsman.
c Leontieff, John	P	1865	1868	—	St. Petersburg	Russian Imperial Navy, St. Petersburg	Lieutenant of Naval Architects.
McAndrew, George	P	1869	1870	—	Low Walker on Tyne		
McCarthy, Michael	A	1866	1870	A[d]	H.M.D., Dvnpt.	H.M. Dockyard, Devonport	Draughtsman.

* The suffixes 1, 2, and 3 denote whether first, second, or third class fellowship. a Sent by the Norwegian Government.
b Sent by the Egyptian Government. c Sent by the Russian Government. d Reported in Official List as having been ill during the examination.

MADE, VAN DER, Dirk Johannes Paulus ...	P	1867	1870	—	Dordrecht	J. M. Van der Made & Co., shipbdrs., &c., Amsterdam	Designer.
MARGETSON, Stewart	P	1864	1865	—	London	Thames Iron Works, Blackwall, E	Draughtsman.
PERRETT, Josiah Richard ...	A	1867	1871	F_2	H.M.D., Dvnpt.	The Admiralty, Whitehall, S.W. (temporarily.)	Draughtsman.
ab PURVIS, Frank Prior	P	1867	1871	F_3	Blackheath	Mr. E. J. Reed, C.B.	Draughtsman.
RAGGE, George Vincent ...	A	1864	—	—	H.M.D., Ptsmth.		*Died in Dec.*, 1866.
RICHARDS, William	A	1865	1868	F_2	H.M.D., Pmbrk.	H.M.D., Pembroke	Draughtsman.
ROWSE, Joseph William ...	A	1865	1868	A	H.M.D., Ptsmth.	The Admiralty, Whitehall, S.W. (temporarily.)	Draughtsman.
c SOBOLEFF, Victor	P	1865	1868	—	St. Petersburg	Russian Imperial Naval Reserve, Sebastopol	Lieutenant of Naval Architects.
STANBURY, George	A	1865	1868	F_2	H.M.D., Dvnpt.	The Admiralty, Whitehall, S.W. (temporarily.)	Draughtsman.
STRICKLAND, Thompson ...	P	1865	1869	—	Bristol		
THEARLE, Samuel James Pope	A	1865	1869	F_3	H.M.D., Dvnpt.	John Elder and Co., Govan	Assistant Overseer for Admiralty.
TREWENT, Francis James ...	P	1866	1869	—	Pembroke Dock.	R. Napier and Sons, Glasgow	Draughtsman.
TRIVESS, Thos. Joseph Geary	A	1867	—	—	H.M.D., Ptsmth.		*Died in March*, 1869.
TRUSCOTT, Henry James ...	A	1866	1870	F_3	H.M.D., Shrnss.	The Admiralty, Whitehall, S.W. (temporarily.)	Draughtsman.
d TURNBULL, Thomas	P	1864	1867	—	Whitby	Whitehall Dockyard, Whitby	Manager.
d VIZETELLY, Adrian	P	1864	1868	A	London	Institution of Naval Architects	Assistant Secretary.
WAMPEN, John Frederic ...	P	1865	1868	—	London	Smith, Pender, and Co., Engineers, Millwall, E.	Draughtsman.
WANHILL, James Manlaws...	P	1865	1865	—	Poole	New Zealand	
WATTS, Philip	A	1866	1870	F_2	H.M.D., Ptsmth.	The Admiralty, Whitehall, S.W. (temporarily.)	Draughtsman.
WHITE, William Henry ...	A	1864	1867	F_1	H.M.D., Dvnpt.	The Admiralty, Whitehall, S.W.	Draughtsman.

MARINE ENGINEERS.

BARRETT, Richard Henry ...	A	1867	1871	F_2	H.M.S.F., Ptsmth.	H.M.S. *Euphrates*	Assistant Engineer.
BEDBROOK, James Albert ...	A	1864	1867	F_3	H.M.S.F., Ptsmth.	H.M. Steam Factory, Keyham	Asst. Inspector of Machinery.
BURT, Henry...	A	1867	1871	F_1	H.M.S.F., Keyham	H.M.S. *Crocodile*	Assistant Engineer.
BENNETT, Alfred Mosley ...	P	1865	1865	—	Liverpool		
CANTER, William James ...	A	1864	1867	A	H.M.S.F. Keyham.	H.M.S. *Zealous*	Engineer.
COW, Douglas	P	1867	1868	—	London		*Left the profession.*

a Obtained School Scholarship. *b* Obtained a Whitworth scholarship. *c* Sent by the Russian Government. *d* Held a Free Studentship.

MARINE ENGINEERS—(*continued*).

Name.	A—Admiralty Student. P—Private Student.	Date of Entry.	Date of Departure.	Diploma. A—Associate. F—Fellow.*	Where from.	Present Employment.	Position held.
DURSTON, Albert John ...	A	1865	1868	F_3	H.M.S.F., Ptsmth.	H.M.S. *Ocean*	Engineer.
a FARLEY, Ephraim Charles ...	P	1865	1869	A	Truro	E. C. Farley, and Co., engineers, Falmouth	Partner and Manager.
GARVEY, John Miller	P	1866	1869	—	London	Henley's Telegraph Works, North Woolwich, E.	Draughtsman.
GRAINGER, James Nixon ...	A	1864	1867	F_2	H.M.S.F., Ptsmth.	Public Works Deprtmt., Madras	Civil Engineer.
GREEN, William	A	1869	—	—	H.M.S.F., Ptsmth.		*Died in June*, 1871.
HARDING, William John ...	A	1865	1868	—	H.M.S.F., Ptsmth.	H.M.S. *Inconstant*	Assistant Engineer.
c HEARSON, Thomas Alfred ...	A	1867	1871	F_1	H.M.S.F., Keyham	H.M.S. *Agincourt*	Assistant Engineer.
HUMMEL, Alphons Alex. Albert Wilhelm Marie	P	1868	1869	—	Bradford-on-Avon	Bourton Foundry, Dorsetshire	Draughtsman.
b IVANOFF, Nicholas	P	1865	1868	A	St. Petersburg	Russian Imperial Navy, London	Lieutenant of Marine Engineers.
LITTLEJOHN, William George	A	1864	1867	A	H.M.S.F., Keyham	H.M.S. *Philomel*	Engineer.
MARES, William Henry ...	A	1868	—	—	H.M.S.F., Ptsmth.		*Died in July*, 1869.
MAYSTON, John Young ...	A	1867	1871	F_2	H.M.S.F., Ptsmth.	H.M.S. *Sultan*	Assistant Engineer.
MORCOM, Alfred	A	1867	1871	F_1	H.M.S.F., Keyham	H.M.S. *Bellerophon*	Assistant Engineer.
PRATTEN, William John ...	A	1864	1867	F_3	H.M.S.F., Wlwich.	Earle's Shipbdg.& Engineering Co. (Limited), Hull	
PRICE, George Arthur... ...	P	1867	1868	—	Wolverhampton	Price and Co., Cleveland Safe Works, Wolverhampton	Partner.
c SENNETT, Richard	A	1866	1870	F_1	H.M.S.F., Keyham	H.M.S. *Crocodile*	Assistant Engineer.
SMITH, David Edward... ...	A	1866	1870	A	H.M.S.F., Ptsmth.	H.M.S. *Euphrates*	Assistant Engineer.
SMITH, Joseph Andrew ...	A	1865	1868	A	H.M.S.F., Ptsmth.	H.M.S. *Chanticleer*	Engineer.
b SOCOLOFF, Vladimir	P	1865	1868	—	St. Petersburg	R.I.S. *Haydamack*	Lieutenant of Marine Engineers.
SOPER, Henry John	A	1865	1868	F_3	H.M.S.F., Keyham		*Left the profession.*
SPENCE, James Carmichael...	A	1864	1867	—	H.M.S.F., Ptsmth.		Manager. [to Naval Cadets.
WARREN, James John... ...	A	1864	1867	A	H.M.S.F., Keyham	H.M.S. *Trafalgar*	Instructor of Marine Engineering
WHELAN, Frederick Astley...	P	1869	1870	—	Dublin	Stonehouse Barracks, Devonprt.	Lieut. Royal Marine Light. Inf.
WHITE, William Henry ...	A	1864	1867	A	H.M.S.F., Wlwich.	H.M.S. *Malabar*	Engineer.
c YEO, John	A	1866	1870	F_2	H.M.S.F., Keyham	H.M.S. *Serapis*	Assistant Engineer.

* The suffixes 1, 2, and 3 denote whether first, second, or third class fellowship.
a Held a Free Studentship. b Sent by the Russian Government. c Obtained a Whitworth Scholarship.

NON-STUDENTS WHO HAVE RECEIVED THE DIPLOMA OF ASSOCIATE OF THE SCHOOL.

Name.	Date of Diploma.	Present Employment.	Position held.
Rich, William E., marine engineer.	1868	Messrs. Easton, Amos, and Co.	Designer.
Watkins, Alfred, marine engineer.	1870	Indestructible Packing Company, Bromley, E.	Partner.

Gentlemen whose names appear in the preceding tables are requested to notify any change of position, &c., during the ensuing year to the Editor, for alteration in the next number of the *Annual*.

THE END.

Associate of the Royal School of Naval Architecture and Marine Engineering. This examination is held annually towards the end of April.

In case of failure at the Examination the student may either remain at the School for another session at a fee of £25, or he may present himself at any future examination whenever he considers himself qualified.

Candidates who have not been students of the School are required to produce certificates that they have been engaged for at least three years in—

1. Practical wood or iron shipbuilding in a Dockyard; or,
2. Practical engine and boiler building in a Dockyard, or in a Marine Engine Factory; or,
3. Practical work as a Draughtsman in a Dockyard or in a Marine Engine Factory, during which the candidate himself must have gone through the complete formation of the design of a ship, or of a marine engine, with the whole of the designs included in it.

Such candidates are also required to give references as to character and good conduct before being admitted to the examination.

All such candidates must apply to the "Secretary, Science and Art Department, South Kensington, W.," not later than the 15th March in each year.

Candidates are examined either as Naval Architects or as Marine Engineers.

SUBJECTS AND MARKS FOR THE DIPLOMA OF ASSOCIATE.

GROUP A.

Naval Architects.	No.	*Marine Engineers.*	No.
Practical shipbuilding	1,000	Practical Engineering	1,500
Laying off	1,000	Proportions and arrangement of marine engines, boilers, and propellers	1,500
Usual calculations of a ship	1,000		
*Elementary physics	1,000	*Elementary physics	1,000
Strength of materials	500	Strength of materials	500
Heat and steam	500	Heat and steam	500
	5,000		5,000

GROUP B.

Naval Architects and Marine Engineers.	No.
Arithmetic and mensuration	1,000
Algebra, including quadratic equations; and Euclid, first six books and 22 propositions of Book XI., with deductions	1,000
†Plane trigonometry and logarithmic calculation	1,000
§Elementary mechanics and hydrostatics	1,000
	4,000

GROUP C.

Naval Architects.	No.	*Marine Engineers.*	No.
‖Ship Drawing	1,000	‖Engine Drawing	1,000
Total marks possible	10,000	Total marks possible	10,000

Note.—Half the possible marks to be obtained in each of the three groups as a condition of the ASSOCIATE'S diploma. The schedule will be revised from time to time as occasion may require.

* An elementary knowledge of chemistry, electricity, and magnetism, with especial reference to the errors of compasses of ships, both of wood and iron.

† Plane trigonometry, as usually read, exclusive of trigonometrical analysis.

§ Including (*inter alia*) the description and explanation of the principal mechanical and hydrostatical instruments and machines, specific gravity, and the flotation of bodies.

‖ The ship and engine drawing will be done by the candidate at home "on honour." Instructions will be sent to any candidate applying in proper time.

Subjects and Marks for the Diploma of Fellow.

Group A.

Naval Architects.	No.	*Marine Engineers.*	No.
Design of a ship	500	Design of a pair of marine engines with boilers and propeller	500
Principles of design of a ship	500	*Principles of design of marine engines, boilers, and propellers	750
Practical shipbuilding and laying off	1,000	†Practical engineering	750
†The steam-engine	500	Practical shipbuilding	500
Heat and steam	500	Heat and steam	500
Strength of materials and structures	750	Strength of materials and structures	750
§Physics	500	§Physics	500
‖Chemistry and properties of metals	750	‖Chemistry and properties of metals	750
	5,000		5,000

Group B.

Naval Architects.	No.	*Marine Engineers.*	No.
¶Pure mathematics	1,500	¶Pure mathematics	1,500
**Applied mathematics	2,000	**Applied mathematics	2,000
Propulsion and resistance of ships and theory of waves	750	Propulsion and resistance of ships and theory of waves	750
Stability and oscillations of ships	750	††Mechanical theory of heat	750
	5,000		5,000
Total marks possible	10,000		10,000

Note.—At least 2,500 marks must be obtained in each of the two groups A and B as a condition of the Fellow's diploma. In case of failure, the examiner will judge whether the knowledge shown by the candidate is sufficient to admit of his being received as an *Associate*.

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* Including a knowledge of the arrangement and proportions of simple and compound marine engines and their appendages; of the mode of representing slide valve motions, and of the use of the indicator; and of the rules for calculating the power of engines and performance of vessels, and the efficiency, evaporation, consumption of fuel, and strength of boilers.

† Including a knowledge of the processes of an engineering factory, of the construction and mode of operation of engines and machinery generally, and of the working of engines on ship-board.

§ Including the elements of pneumatics, electricity, and magnetism, with its application to ships, both of wood and iron.

‖ A fair knowledge of inorganic chemistry and qualitative analysis.

¶ The pure mathematics will involve a fair knowledge of the calculus, including (*inter alia*) the elementary parts of calculus of finite differences, and of the calculus of variations, and of differential equations, of analytical geometry of three dimensions, and of descriptive geometry, a thorough acquaintance with the principles of the mensuration of shipbuilding [or marine engineering].

** The applied mathematics will include such subjects as are chiefly useful to naval architects and marine engineers, such as statics, dynamics, hydrostatics, hydrodynamics, theory of internal stress and of elasticity, with the applications of these subjects to the strength of materials and structures, and to machinery.

†† In its application to the theory of the steam-engine.

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